CHAPTER II
GUNNERY

Section I. INTRODUCTION

79. (U) General

a. This chapter is a guide for the Redstone group commander and his staff on field artillery gunnery for the Redstone group. It prescribes procedures for fire direction, computation of firing data, and fire commands.

b. The primary characteristics of the Redstone are its long range and nuclear firepower capabilities. To be effective, this fire must hit the target at the *right time*. Field artillery doctrine demands delivery of accurate fire within time limits imposed by the tactical situation. Procedures must insure maximum reliability, flexibility, and timeliness in the execution of nuclear fire missions.

c. Much of the information contained in this chapter is based on standard artillery doctrine; however, the information dealing specifically with fire direction procedures and computation techniques is based on data available at the time of publication of this manual.

80. (CM) Trajectory

a. Phase I From Liftoff to Cutoff. The missile is fired vertically from point A_0 (fig. 15). The missile ascends initially at a relatively low speed. Because of this low speed, little or no control is provided by the rudders. Carbon vanes, located in the jet exhaust of the propulsion unit, direct the expulsion of the hot gases and provide control and stability during the initial stage of this phase of the flight. Also, during this period, lateral deviations are detected by the lateral accelerometer and correction commands are sent to the control surface by the guidance system. Although range guidance as such is not in effect at this time, deviations in velocity and displacement are utilized in the cutoff computer, which determines cutoff when preset conditions are satisfied. The deviations that exist in range for the entire trajectory and laterally after cutoff are accumulated in the range and lateral computers and are fed to the control computer after reentry.

b. Phase II From Cutoff to Separation. At point A_1 (fig. 15), conditions permit the cutoff equation to be satisfied, and the propulsion unit is cut off. Cutoff is chosen so that the missile is traveling at a certain velocity at a certain point in space, so as to follow a predetermined ballistic trajectory in to the target. Between cutoff and separation

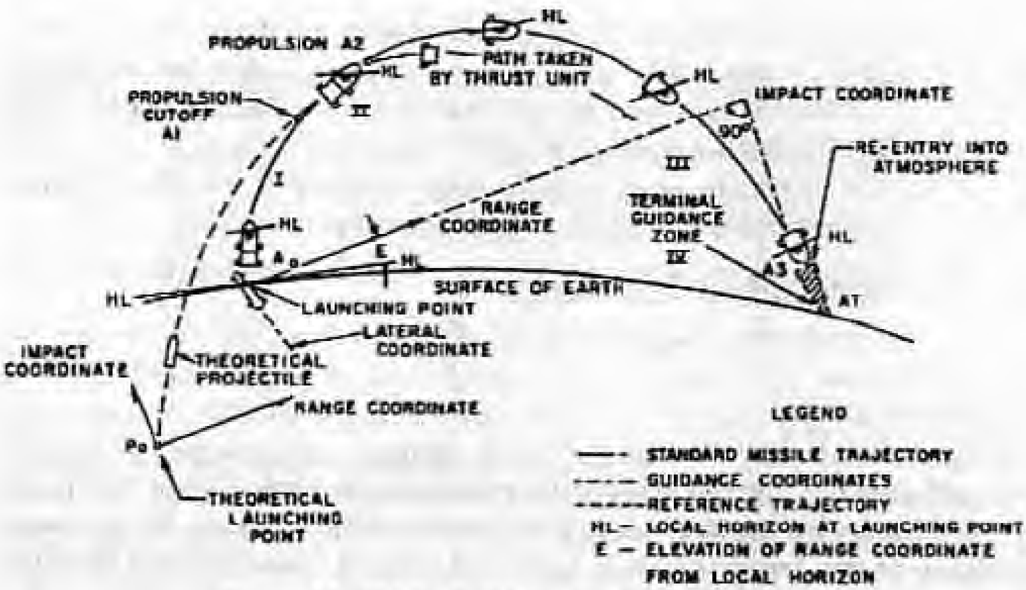

Figure 16. (CM) *Redstone standard trajectory.*

of the thrust unit from the body, there is a delay of some 10 to 30 seconds. Up to point A_1, the missile has been under a constantly increasing acceleration. As a result, time must be provided for the acceleration to fall to zero and the velocity to stabilize. This is called thrust decay. The time between cutoff and separation has been delayed in order to prevent the thrust unit from colliding with the missile body during thrust decay. At point A_2, separation is completed, and the thrust unit follows closely behind the body. Because of little atmospheric density at this altitude (approximately 175,000 to 275,000 feet), the air vanes on the body are ineffective, and jet nozzles provide attitude control.

c. Phase III From Separation to Reentry. During phase III, the body follows a ballistic trajectory controlled in attitude by air jets. From separation to reentry, the range and lateral computers continue to accumulate deviations from the standard trajectory.

d. Phase IV From Reentry to Impact. Reentry (approximately 300 seconds from liftoff for minimum range to 340 seconds for maximum range) is the point on the trajectory where the body unit of the missile comes back into that portion of the earth's atmosphere which is sufficiently dense to activate a deceleration switch. This is a critical period, since extreme heat and shock are generated as the body dives into denser air. One of the primary reasons for separation is to improve aerodynamic stability of the missile body during this phase. Also, without separation, heavy construction of the thrust unit would be required in order to withstand rapid deceleration and maneuver accelerations. On reentry, the deceleration switch initiates the following guidance and control changes:

(1) The control computer accepts signals from the lateral and range computer. The guidance system gain is small at

first, and then it gradually increases until the control servo loop is operating at full gain. Possible destruction of the missile would occur if corrections were enforced too abruptly at this high velocity.

(2) The attitude error signals are attenuated so that primary consideration is given to guidance errors.

81. (CM) Standard Trajectories

a. The standard trajectories for the entire range of 93 to 324 kilometers are obtained by using 2 different tilting programs during the powered portion of the trajectory. These tilting programs are designated as short range and long range. The range covered by trajectories having the same tilting program is varied from maximum to minimum by cutting back the burning time. Thus, the powered portion of any trajectory in a family of related trajectories is identical except for time of cutoff.

b. Fourteen tapes representing standard trajectories are used in conjunction with the tilting programs. These tapes are carried in the test station. The correct tape is determined during the computation of the firing commands.

c. From firing until impact, the attitude of the missile in the pitch plane is controlled by the recorded program. This is done in order to insure proper pitch attitude of the missile throughout its trajectory.

Section II. THE GUNNERY PROBLEM

82. (CM) General

a. The Redstone missile gunnery problem is one of determining equipment settings which will cause the missile to deliver its warhead to the target. These equipment settings or presettings represent the fire commands which are sent to the firing position and placed in the missile prior to firing.

b. These presettings establish a precalculated standard trajectory in the missile guidance equipment. Missile performance is compared with this standard trajectory to determine any corrective maneuver necessary after reentry. Missile performance is measured by two gyro accelerometers which measure accelerations in the direction of their sensitive axes.

c. A knowledge of the guidance and control system is needed to understand the theory of the firing tables and the purpose of the presettings.

83. (CM) Firing Table Theory

a. The path or trajectory of the missile can be described by equations of motion which consider the forces affecting the missile throughout its trajectory. Since these forces are vector quantities, a reference or coordinate system is established. The basic trajectories for

the Redstone missile are calculated with reference to a space-fixed Cartesian coordinate system (rectangular, three-dimensional). The reference of this system is the earth's center, with the Y axis going through the launcher location. The X and Y axes are in the plane of the trajectory, and the Z axis is perpendicular to the plane of the trajectory (fig. 16). This space-fixed coordinate system is further referenced to an earth-fixed coordinate system, which has its origin at the launcher location. This is done to simplify the transformation of equations of motion to the missile guidance coordinate system. The earth-fixed coordinate system is a direction-fixed coordinate system with a constant velocity equal to the velocity imparted to the launcher location by the rotation of the earth.

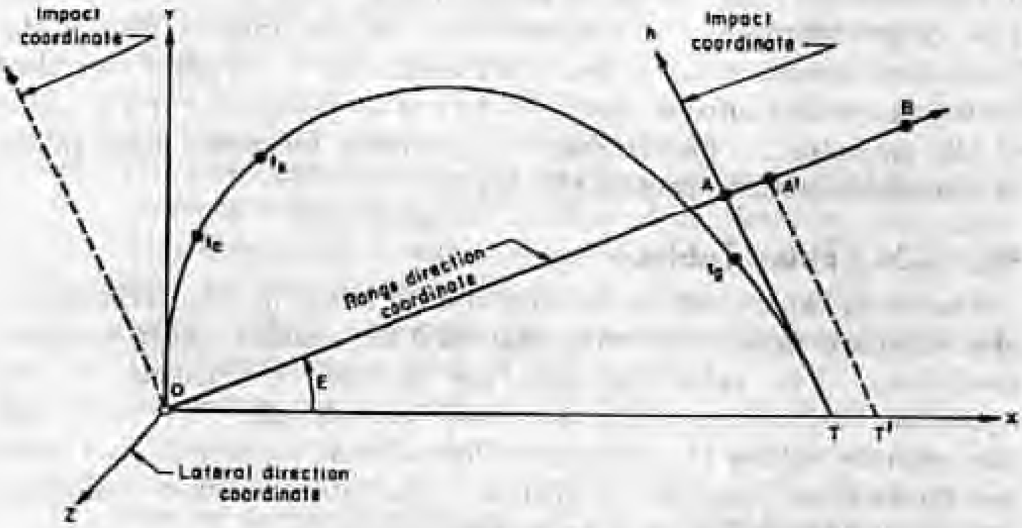

Figure 16. (CM) *Redstone standard trajectory, X, Y, and Z and guidance coordinates.*

b. The missile guidance coordinate system establishes the measuring axes as the range direction coordinate and lateral direction coordinate. The values for missile presettings are determined along these two measuring axes (fig. 16).

c. Referencing of the space-fixed coordinate system to the launcher location and the transposition to the missile guidance coordinate system is not apparent in the firing table solution of the gunnery problem.

d. With the Redstone system, the standard and reference trajectories must coincide at cutoff. Coincidence is accomplished by selecting a program tape and appropriate missile guidance coordinate directions. The tape is selected based on the computed range and provides coarse range control. The guidance coordinate directions were selected to provide optimum accuracy and simplicity in fabrication of guidance equipment. The selections of the coordinate direction and tape minimize errors due to time of flight variations and result in a free flight path after cutoff.

e. The range control generated by the tape causes the missile to follow a path approximating the standard trajectory with minimum angle of attack. When the guidance system is influenced by the presettings, this path will theoretically coincide with the standard trajectory at cutoff.

f. The guidance coordinates are referred to as range, lateral, and impact. No measurements are made in the impact coordinate direction since deviations in the impact direction result in only second-order errors, which are negligible. The impact coordinate is defined as the tangent to the trajectory at the point where those forces parallel to the range coordinate are equal and opposite. The range direction coordinate is defined as a line extending through the launcher in the direction that the range accelerometer measures accelerations. The range coordinate is perpendicular to the impact coordinate. The lateral coordinate direction is perpendicular to the plane described by the range and impact coordinates or is perpendicular to the plane of the trajectory. The lateral accelerometer measures acceleration of the missile with respect to this plane.

84. (CM) Firing Tables

The firing tables contain tabulated data based on the performance of a standard missile following standard trajectories under standard conditions. The tabulated data are actually coefficients for the equations used in computing the missile presettings. The tables will also contain values to compensate for altitude variations and other deviations from standard conditions. The tables contain coefficients listed under the following parameters:

a. R_h—argument to determine interpolation factor.

b. R—range angle value used to compute time to enter other tables.

c. K—aiming azimuth.

d. E—elevation angle for range accelerometer.

e. A—correction factor applied to velocity (Q).

f. B—correction factor applied to displacement (S).

g. TT—total flight time.

h. C—correction to TT.

i. W, F, SI, ST—factors to be used to compensate for variations in liftoff weight, thrust, and specific impulse.

j. Q—velocity presetting.

k. S—displacement presetting.

l. T—cutoff equation constant.

m. N—cutoff equation constant.

85. (CM) Functions of the Missile Presettings

a. General.

(1) These presettings are placed in the missile or launcher prior to firing. They provide the reference values for detecting

deviations of the missile from its precalculated standard trajectory.

(a) K—aiming azimuth.
(b) T—cutoff constant (set in by L).
(c) N—cutoff constant (set in by M).
(d) E—elevation angle for range accelerometer (set in by P).
(e) Q—velocity setting (set in by I).
(f) S—displacement setting (set in by J).

(2) The presettings serve as the intelligence for the missile guidance and control systems. As the missile travels along the trajectory, its position is determined relative to these preset values. Variations in velocity and displacement are determined by the range and lateral gyro accelerometers along the respective measuring axes. The purpose of the range and lateral components of the guidance system is to guide the missile, so at the completion of terminal guidance the trajectory passes through the target.

(3) The gyro accelerometer is constructed so that the output presents a first integration value of acceleration with time. This determines a value of velocity in meters per second. This velocity is transmitted to a separate guidance component which performs the second integration with time. This determines a value of displacement.

(4) The values for velocity, displacement, two cutoff equation constants, and the elevation angle E are determined so that all integrator outputs are zero or close to zero at the start of terminal guidance. Terminal guidance is initiated by a deceleration switch which measures the deceleration in the direction of the longitudinal missile axis. At this time, if integrator outputs are not zero, the remaining values are cleared out and sent to the rudder servo system.

b. *Explanation of Laying Azimuth K.*

(1) Prior to the determination of the values of velocity, displacement, two cutoff equation constants, and the elevation angle E, it is necessary to determine a value for the laying, or aiming azimuth K. In discussing the laying azimuth, it is necessary to consider the relationship between the target and launcher as the earth rotates.

(2) The relationship of the launcher location and the target with the effect of the earth's rotation on these points is shown in figure 17. This illustration indicates a northwest firing direction showing the earth's velocity vector V_L for the full time of flight applied at the firing location (FP_1). The length of this vector represents the distance FP_1 will move (referenced to space) during the time from launch until impact, i.e., to FP_2. If the azimuth (K_T) from FP_1 to T_1

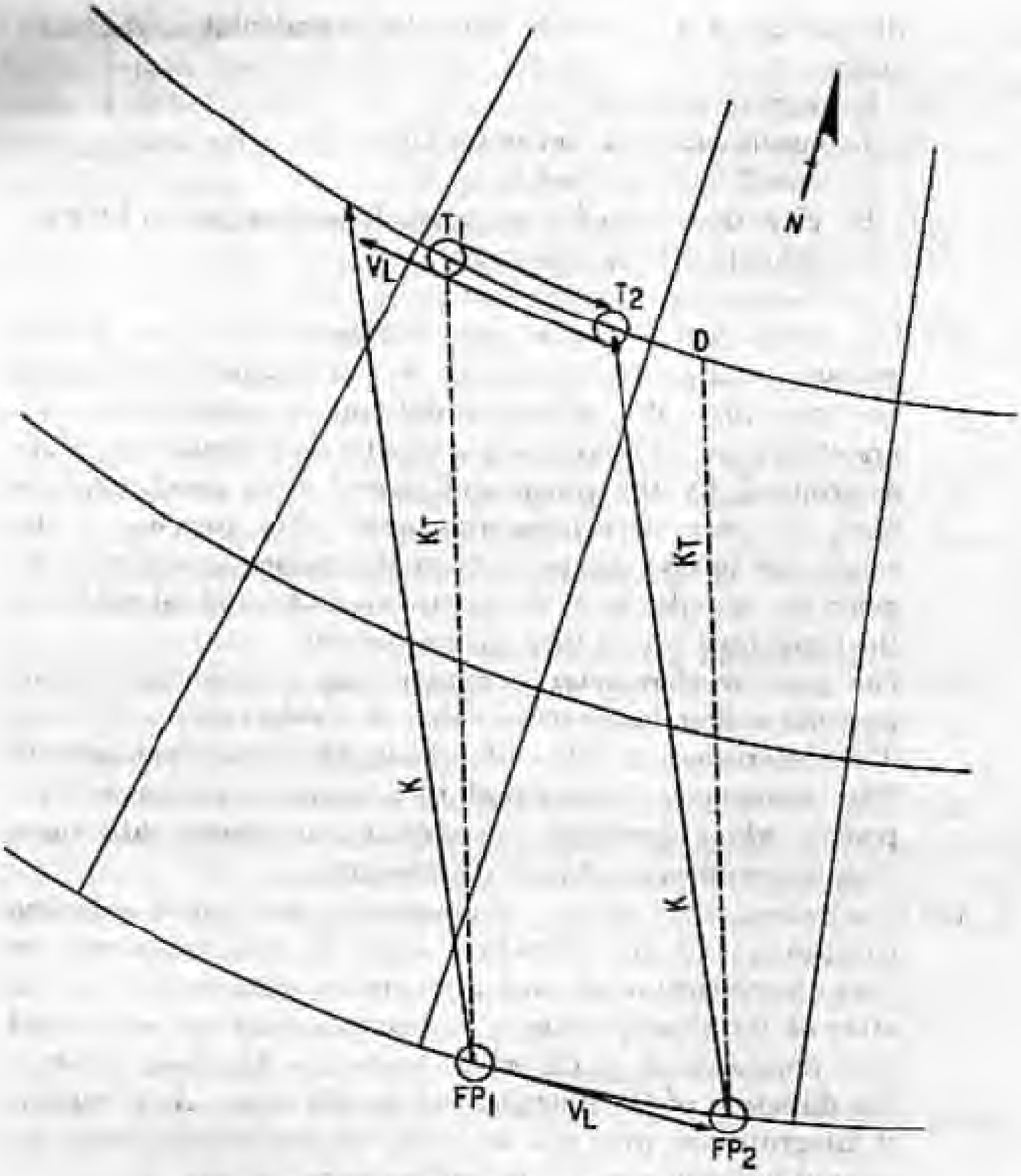

Figure 17. (CM) *The effect of the earth's rotation.*

(Target Location at time of Launch) were used as the aiming azimuth the missile would impact at point D. However, T_1 traveling at a lower velocity has only moved to T_2 during the elapsed time causing a miss distance equivalent to the vector shown between T_2 and Point D. To determine the proper aiming azimuth, the velocity vector V_L is applied opposite the earth's rotation at the predicted target (T_2) and a correction is applied to K_T producing aiming azimuth (K). Rotational effects and latitude differences also influence range computations. These factors are reflected in the cutoff equation and in the range computations.

(3) One situation where the rotation of the earth does not affect the trajectory is the case where the missile is fired at a terrestrial target from the North Pole. Since the Pole has

no velocity due to the rotation of the earth, the trajectory will be the same as one being fired from a nonrotating earth. The target, on the other hand, has a velocity relative to space, so that the missile which is fired to strike a target T3 actually hits a target T4, since the earth has rotated the target position through an angle (angular velocity × time) during the time of flight. The solution then is to assume the target to be T4 and aim at target T3.

(4) Under actual conditions, time of flight variations up to 10 seconds, due to winds, thrust, etc., can be expected. The error in hitting a target is equal to the velocity of the target multiplied by the change in time of flight. For example, a missile fired from the North Pole to a target on the Equator (velocity 460 meters per second (m/s)) would produce a maximum error of 4,600 meters (10 sec × 460 m/s=4,600 meters).

c. Explanation of the Elevation Angle (E). The Redstone guidance system is a two-component guidance system. One measuring direction is the range direction coordinate, and the other measuring direction is the lateral direction coordinate. Errors are expressed as a function of flight time variation. The explanation of these errors and the manner in which they are compensated for are explained as follows (fig. 16):

(1) There are two types of forces that act upon a missile from launcher to target:

(*a*) Inertial forces which are measurable.

(*b*) Gravitational anomalies.

(2) The total distance the missile travels from the launcher location to impact, as measured along the range axis, is shown in figure 16 as the distance from O to B. The distance the missile travels, due to inertial forces, is represented by the distance OA. The distance AB is due to the effect of the gravitational field. The distance OB may be kept constant by the guidance system since it can be precalculated. The distance BA varies with the individual firings. A possible distance is represented by A′B with corresponding impact error at T′. The problem of accounting for these unmeasured accelerations is solved by precalculating these accelerations for standard conditions of a given trajectory and applying them to determine proper impact data.

(3) Since gravity accelerations depend on the actual position occupied by the missile in the trajectory, nonstandard conditions will not allow these gravity accelerations to coincide with precalculated accelerations. The nonstandard conditions result in changes in the actual time of flight of the missile which, in turn, changes the actual time of flight

as compared to the precalculated value. There is a close correlation between this change in time of flight and change in the gravity accelerations. This correlation of errors is used as a basis to derive correction terms to compensate for errors in range which would otherwise result from nonstandard conditions.

(4) The errors encountered in time of flight variations are divided into first- and second-order errors. The first-order errors are overcome by the proper selection of the elevation angle E, velocity, and displacement preset values. The correction for second-order errors is disregarded because of the small effect of these errors. The elevation angle E is such that the range measuring component of the drag effect is as small as possible during terminal guidance.

d. Explanation of the Presettings Velocity (Q) and Displacement (S). Q and S represent the velocity and displacement values the missile should experience, along its trajectory on the range axis, from launch until terminal guidance is initiated at reentry. They are calculated so that the velocity at cutoff, when integrated with respect to time over the period from cutoff to reentry, tends to cancel displacement, resulting in a near zero output from the range computer. The characteristics of the guidance hardware are such that velocity is preset with a negative value and displacement is preset with a positive value.

e. Explanation of Presettings T and N (Two Constants in the Cutoff Equation Preset Through L and M).

(1) Before firing, both the anticipated points of terminal guidance and cutoff are only approximations, since they are determined by the peculiarities of the particular trajectory. The exact point of cutoff is determined through solution of a cutoff equation in the cutoff computer. The cutoff computer is located in the range computer and is physically geared to operate from the same signal sources.

(2) The cutoff equation is as follows:

$$\frac{\Delta S}{T}+\Delta Q+N=0$$

where ΔS = displacement value remaining in the cutoff computers;

ΔQ = velocity value remaining in the cutoff computer;

T = cutoff equation constant representing the time of flight from standard cutoff to starting time of standard terminal guidance (preset using L).

N = cutoff equation constant representing correction values for thrust, decay, separation, and drag. These values are determined from standard cutoff to starting time of standard terminal guidance (preset using M).

(3) The preset values T and N are obtained by starting with zero values at reentry and integrating the forces involved with time back to the launcher location.

(a) T is obtained by determining the time between standard cutoff and starting time of standard terminal guidance. This time constant is sufficiently accurate to be set into the cutoff computer.

(b) N is obtained by determining the values for the following:

1. Decrease in velocity to compensate for thrust decay since cutoff is not instantaneous but requires a period of approximately 0.38 second.

2. Increase in velocity to compensate for losses due to drag from cutoff to reentry.

3. Velocity value in the range-measuring direction due to forces involved in separating the body unit from the thrust unit.

(4) When standard conditions do not prevail, the cutoff equation attempts to make the value of the displacement integrator plus the displacement presetting equal to zero at terminal guidance. Any displacement value present at reentry is canceled by the maneuver during terminal guidance.

Section III. GROUP FIRE DIRECTION

86. (U) General

a. The fire direction center is that element of the command post by which the commander exercises fire direction control. It consists of gunnery and communication personnel who assist the commander in the control and coordination of fires. The fire direction center personnel convert fire missions from higher headquarters into appropriate fire commands for the firing batteries. The fire direction center personnel control the execution of fire missions.

b. Accuracy, flexibility, and speed in executing fire missions depend on—

(1) Accurate and rapid preparation of firing data.

(2) Transmission of fire commands directly to the firing batteries as soon as determined.

(3) The efficient assignment and division of duties among fire direction personnel.

(4) The adherence to a standard technique.

(5) The efficient use of mechanical devices, such as the calculating machine.

(6) Fire direction personnel functioning as a team and operating in a definite sequence.

87. (U) Personnel

a. Personnel in the fire direction center include the S3, two assistant S3's, chief fire direction computer, assistant chief fire direction computer, five fire direction computers, and such other members of the operations and intelligence platoon as may be required. The S3 is the gunnery officer of the group. Other officers of the group staff should be trained to relieve the S3 when necessary.

b. General duties of personnel in the fire direction center are as follows:

(1) The S3 plans, coordinates, and supervises the activities of the fire direction center and is responsible for training the personnel. On receipt of a fire mission, he alerts the firing batteries. The assistant S3's are the chief assistants, relief, and replacements for the S3.

(2) The assistant S3 in charge of the fire direction center supervises and trains the fire direction computers and actively supervises the computation of fire mission data and its transmission to the firing battery.

(3) The fire direction center personnel prepares and maintains a fire capabilities chart.

(4) The chief fire direction computer supervises, checks, and reconciles the computations of the fire direction computers and supervises transmission of data to the firing batteries.

(5) Computers determine and read firing data based on information contained in the fire mission and basic data.

88. (U) Fire Capabilities Chart

The fire capabilities chart is a 1:250,000 or smaller scale map containing information similar to that on the fire capabilities chart and situation map in other field artillery units. The chart is designed to show the S3, at a glance, information necessary for fire orders and safety. This chart shows locations of targets, zones of fire, bomb lines, and no-fire lines, as well as the tactical situations of both enemy and friendly forces. Standard artillery symbols and colors are used.

89. (U) Basic Data

a. Basic data for computations are received at the fire direction center from various sources. Computers record these data on the fire direction center basic data record (fig. 18) and the fire command sheet (fig. 19).

b. Survey personnel report survey data to the fire direction center as data become available. The survey data consist of the universal transverse mercator (UTM) grid zone on which the survey is based, the grid coordinates and/or geographic coordinates and the height (altitude) of each firing position, and the grid azimuth of orienting line.

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FDC BASIC DATA RECORD

Received From: *Army FDC*
Received By: *Sp Jones*
Date and Time: *060520Z Apr*

Fire Mission		Survey Data	
Identification	*Hawk 3*	Battery to Fire	*A*
Concentration Nr	*AB 21*	Firing Position	*F*
Date and Time to Fire	*061630Z Apr*	Grid Azimuth of OL	*116° 27' 42"*
Type Warhead	*Y 1*	Convergence (line 34, WS1)	*±2°22'49"*
Type Burst	*Air*	Geodetic Azimuth of OL	*114°04'53"*

Missile Data

Missile Nr	*2001*	Liftoff Weight	*61,884*
Calibrated Thrust	*78 000*	Alcohol Temperature	*−25°*
Calibrated specific impulse	*216.7*		

Firing Position	*(1) GEOGRAPHIC COORDINATES (Code −1)	Target
(2)	Latitude	(4)
(3)	Longitude	(5)
(6)	Altitude	(7)

Firing Position	*(1) UTM COORDINATES (Code+1)	Target
(9) *346 309*	Easting	(11) *653 368*
(8) *6 646 963*	Northing	(10) *6 654 755*
(6) *1235 M*	Altitude (14) Spheroid	(7) *730 M*
(12) *44*	Zone	(13) *44*

STATUS DATA

Mission Assigned to Battery ______ Missile Nr ______

Code, Date and Time Completed

M	A	J	K	H	L	O	F	B	C	X	
Ø	Ø	Ø	Ø	Ø	Ø	Ø			Ø		
6	6	6	6	6	6	6			6		
Ø	1	1	1	1	1	1			1		
9	Ø	1	2	4	3	5			4		
3	4	2	3	1	3	Ø			2		
Ø	5	Ø	Ø	Ø	5	2			Ø		

*Number in parentheses correspond to input code numbers for the missile firing data computer (Redstone)

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Figure 18. (CM) *Example of fire direction center basic data record.*

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Worksheet 16

FIRE COMMAND SHEET

Battery A

Firing Position F

Concentration Nr AB 21

Type Warhead Y1

Missile Nr 2001

Date and Time to Fire 061630Z Apr

*Geodetic Azimuth of Orienting Line 114° 04 53"

**Presettings:

15.	Tape Number (From Firing Table)	13
16.	K (From WS 5)	84° 51' 34.6"
17.	L (From WS 13)	702
18.	M (From WS 13)	576
19.	X (From WS 6)	478
20.	Y (From WS 6)	933
21.	Z (From WS 6)	750
22.	E (From WS 6)	38.2
23.	F (From WS 14)	118.711
24.	F + .01 (From WS 14)	118.685
25.	F - .01 (From WS 14)	118.737
26.	H (From WS 15)	0.416
27.	H + .01 (From WS 15)	0.587
28.	H - .01 (From WS 15)	0.245
29.	I (From WS 14)	364.516
30.	J (From WS 14)	234.442
31.	O (From WS 11)	- 2210.839
32.	S (From WS 12)	166.679
33.	P (From WS 6)	58
( )	Alcohol Temperature	- 13.4

*Grid azimuth of orienting line plus or minus convergence (Line 34 WS 1).

**These numbers correspond to the output code numbers for the Missile firing data computer (Redstone).

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Figure 19. (CM) *Example of fire command sheet.*

90. (U) Status and Readiness Charts

At the completion of each major step of operation required in preparing a missile to be fired, the firing battery commander will render a report to fire direction center. This data will be recorded on an appropriate chart (fig. 20). The chart enables the S3 to determine the status of each firing battery in relation to each assigned mission. A prearranged code can be used in transmitting this data, but the code must be changed frequently enough to preclude compromise.

91. (U) Fire Mission

A separate fire mission for each missile to be fired is received from the army fire support coordination section. The fire mission should contain the following elements: Warning, identification, concentration number, date and time to fire (or time on target), type of warhead, height of burst, target location, altitude of target, and nature of target. Items in *a* through *i* below pertain to elements of the fire mission.

a. Warning—The army FSCS should send a warning order of an impending fire mission to the group as early as possible prior to the desired time to fire.

b. Identification—Designation of the higher artillery headquarters ordering the fire mission.

c. Concentration Number—Identification of mission by letter group and number system.

d. Date and Time to Fire—Greenwich civil time. The army artillery fire direction center must insure that the desired time to fire is within the capabilities of the group, considering the state of readiness.

e. Type of Warhead—Depends on tactical situation.

f. Type of Burst—Depends on tactical situation.

g. Target Location—Because of the range of the missile, the target location must be a complete reference, including the universal transverse mercator, grid zone designation, the 100,000 meter square identification, and the coordinates to the nearest meter. If the missile firing data computer, Redstone, is to be used to determine firing data, either UTM grid or geographic coordinates are acceptable.

h. Altitude of Target—Meters above mean sea level.

i. Nature of Target—This element of the fire mission is not mandatory but is highly desirable. Informing personnel of the general nature of the target of which they are firing is an important morale factor.

MISSILE NR	TIME TO FIRE	MISSILE DATA: LIFTOFF WEIGHT	MISSILE DATA: CALIBRATED THRUST	MISSILE DATA: SPECIFIC IMPULSE	MISSILE DATA: ALCOHOL TEMPERATURE	STATUS: READY STORAGE	STATUS: BATTERY	CODE H: MATING COMPLETED	CODE Q: HORIZONTAL CHECKOUT	CODE V: ERECTION COMPLETED	CODE Z: PROPELLANT LOADING ALC	CODE A: PROPELLANT LOADING LOX	CODE F: PROPELLANT LOADING H_2O_2	CODE Y: LAYING COMPLETED	CODE B: VERTICAL CHECKOUT	CODE I: START LOX REPLENISHING	CODE J: AREA CLEAR	REMARKS
2001		61,889	78,000	216.7	-25°	A	A	0930 6 Apr	1045 6 Apr	1120 6 Apr	1230 6 Apr	1410 6 Apr	1425 6 Apr	1502 6 Apr		1410 6 Apr		Informed Gp of status 1500 hrs
2002		61,902	77,900	216.3	-25°													
2003		62,004	78,000	217														A Btry pick up at 1900 hrs 6 Apr
2004		61,900		217.1														

Figure 20. (U) Example of status and readiness chart.

92. (U) Fire Control Procedures

A fire mission received from the army fire support coordination section is decoded, and personnel in the group fire direction center perform the following operations in the sequence listed:

a. Computers enter all firing data directly obtainable from the fire mission on the fire direction center basic data record (fig. 18) and the fire command sheet (fig. 19).

b. Simultaneously with action in *a* above, the target location is plotted on the fire capabilities chart.

c. The S3 determines which battery will fire by using the information contained on the status and readiness chart in conjunction with the group commander's policy. The S3 immediately alerts the firing battery(ies).

d. Computers determine firing data.

e. The S3 transmits firing data to the firing battery by messenger or other communication channels. At times, it may be necessary to encode certain fire commands by using a prearranged message code. All personnel should be trained so that the use of such a code does not delay the execution of a fire mission.

(1) If the missile programing data computer is used for determining firing data, all firing data is transmitted at once to the firing battery.

(2) If the firing data are computed by the longhand method, initial data may be transmitted to the firing battery in fragmentary form.

93. (CM) General

Firing data may be computed by using the missile programing data computer or by computers using the longhand computation method. The longhand method requires approximately 2 to 3 hours. Since the missile programing data computer requires approximately 10 minutes overall warmup, testing, and computation time, this method will be used whenever possible. During cold weather, warmup time might become considerable, causing an increase in the 10 minute overall time. To overcome this the computer van could be stored in a heated shelter or a source of heat improvised in the van itself. Fire direction personnel must, however, be proficient in the use of the longhand method to provide for situations in which the missile programing data computer is inoperable or not available.

94. (U) Computation of Firing Data Using Missile Programing Data Computer

The missile programing data computer is a compact, transistorized, general purpose, digital computer, which has been programed to solve the Redstone gunnery problem. The following procedure is used:

a. The operator presses the "On" button and waits until the "Ready" light glows (approximately 40 seconds).

b. The operator presses the "Test" button, and the computer proceeds to solve a test problem, the parameters of which have been included in the program. If the computer is operating correctly, the typewriter will print the test problem solution with an extra line below the last output item. If this extra line contains no digits other than zero, the computer is operating satisfactorily.

c. The operator presses the "Setup" button. This operation conditions the computer to accept the parameters for the particular problem to be solved.

d. Using the keyboard on the control panel, the operator enters the parameters of the particular problem to be solved in accordance with the formats shown in figure 21. The first parameter is either a +.1 or a −.1 which indicates to the computer whether the locations of target and firing position are in UTM (+.1) or geographic (−.1) coordinates. The formats shown in figure 21 are required to permit the computer to accept all possible parameters. The computer is being reprogramed to compute the recent change in the gunnery solution. This will require lift-off weight, calibrated thrust, engine specific impulse, and alcohol temperature as an input. No data is presently available on this change.

e. As each digit is entered from the keyboard, a corresponding neon "nixie" tube will light in the display portion of the control panel, indicating the digit which has been entered. As soon as all

MISSILE FIRING DATA COMPUTER (REDSTONE) - INPUT FORMATS

Code	Geographic Coordinates	Sign	Indicator
1		±	.1
	F I R I N G P O S I T I O N		
2	Latitude	±	XXX. XX. XX. X
3	Longitude	±	XXX. XX. XX. X
6	Altitude	±	X XXX. X
	T A R G E T		
4	Latitude	±	XXX. XX. XX. X
5	Longitude	±	XXX. XX. XX. X
7	Altitude	±	X XXX. X
	UTM Grid Coordinates		
1		+	.1
	F I R I N G P O S I T I O N		
9	Easting	+	X XXX XXX. X
8	Northing	±	XX XXX XXX. X
6	Altitude	±	X XXX. X
12	Zone	+	XX. X
	T A R G E T		
11	Easting	+	X XXX XXX. X
10	Northing	±	XX XXX XXX. X
7	Altitude	±	X XXX. X
13	Zone	+	XX. X
14	Spheroid	+	0. X

Input Format

-1		1
+059. 55. 48. 000		2
+281. 45. 00. 000		3
+	1235. 0	6
+060. 00. 00. 000		4
+276. 15. 00. 000		5
-	71. 0	7
-		

+1		01
+	345109. 00	09
+	4646953. 00	08
+	1235. 0	6
+	44. 0	12
+	653368. 00	11
+	4654735. 00	10
-	73. 0	7
+	44. 0	13
+	0. 1	14

Spheroid Indicators

International	+0. 1
Clark 1866	+0. 2
Everest	+0. 3
Clarke 1880	+0. 4
Bessel	+0. 5

Figure 21. (CM) *Example of input format, missile firing data computer, Redstone.*

digits in the parameter have been entered at the keyboard, the operator can check the nixie display to determine if the proper value has been entered. If the operator has made an error, it can be corrected by pressing the "Clear" key and reentering the parameter. When the parameter is displayed correctly, the operator presses the "Parameter" button. In a few seconds, the computer stores the parameter, provides another nixie display to show what has been stored, and causes the typewriter to print a record of the parameter. After checking the nixie display for correctness, the operator depresses the "Clear" key, and the computer is ready to accept the next parameter. If an error is discovered after the computer has stored the parameter, the operator must press the "Setup" button and start the problem again.

f. After all the parameters have been stored in the computer, the operator presses the "Parameter" button once more, and the

computer starts computation of the problem. If UTM grid coordinates have been used, the computer will display and print the geographic coordinates of the firing position and the target and then halt (fig. 22). These geographic coordinates are a by-product of the UTM coordinate solution. To proceed with the computation of the remainder of the problem, the operator once again presses the "Parameter" button.

MISSILE FIRING DATA COMPUTER (REDSTONE) - INTERMEDIATE UTM OUTPUT

Code		Intermediate Output
2	Firing Position Latitude	+059.55.47.980 2
3	Firing Position Longitude	+281.44.59.998 3
4	Target Latitude	+059.59.59.993 4
5	Target Longitude	+276.14.59.936 5

Figure 22. (CM) *Example of intermediate UTM output, missile firing data computer, Redstone.*

g. When the computer has completed the problem, it will display and print the 19 items shown in figure 23. (A proposed change in the computer program will provide the value of "C", the convergence at the firing position, as an additional output. This is entered on the basic data record (fig. 18) and used to convert the grid azimuth of the orienting line to a geodetic azimuth, see paragraph 101*c*(2).) Each of these items is identified by a code number corresponding to the numbers on the fire command sheet (fig. 19).

h. After computation of a particular problem, the operator again presses the "Test" button to determine if the computer is still in operating condition. If the last line of the test problem solution contains no digits other than zero, it is assumed that the computer operated satisfactorily throughout the computation of the actual problem.

i. The key marked "Enter" is never used during the solution of a Redstone problem. If it is depressed inadvertently, the operator should press the "Setup" button and again enter parameters.

95. (U) Determination of Firing Data Using the Longhand Solution—General.

a. Computers obtain elements of firing data from the firing mission, firing tables, and basic data. Two computer teams check their computations with each other at logical points. The chief fire direction computer checks and resolves differences in computations to eliminate errors as quickly as possible.

b. All personnel in the fire direction center must know the arrangement of the firing tables and how to use them. An explanation of the

MISSILE FIRING DATA COMPUTER (REDSTONE) - OUTPUT FORMATS

Code	Presetting	Output Format		
15	Tape Number	+	13	15
16	K	+	084.51.24.742	16
17	L	+	700.9	17
18	M	+	575.0	18
19	X	+	478.	19
20	Y	+	933.	20
21	Z	+	750.	21
22	E	+	38.2	22
23	F	+	118.711	23
24	F + .01	+	118.685	24
25	F - .01	+	118.737	25
26	H	+	0.4162	26
27	H + .01	+	0.5874	27
28	H - .01	+	0.2450	28
29	I	+	364.184	29
30	J	+	234.264	30
31	Q	-	2208.83	31
32	S	+	166426.	32
33	P	+	58.0	33

Figure 28. (CM) *Example of output format, missile firing data computer, Redstone.*

use of the firing tables, together with sample problems, is contained in the introduction to the firing tables. Fire direction personnel must also know how to use the calculating machine.

96. (U) Composition of Firing Data

Firing data is composed of—

a. Basic data.

b. Preliminary presettings.

c. Conversion of presettings to missile settings and calibration factors.

97. (U) Equipment

The following equipment is needed to compute firing data:

a. Trigonometric functions, seven-place (argument in decimals or degrees).

b. TM 5–241–2 (universal transverse mercator grid; zone to zone transformation tables).

c. Tables for transformation of coordinates from grid to geographic for the appropriate spheroid (TM 5–241–3/2, International; TM 5–241–4/2, Clark 1866; TM 5–241–5/2, Bessel; TM 5–241–6/2, Clark 1880; TM 5–241–7/2, Everest).

Note. The publications in *c* above are the new designations for the volumes II of Army Map Service Technical Manuals (AMSTM) 6, 7, 8, 9, and 11, respectively.

d. Tables for radii vector for the appropriate spheroid, see firing tables.

e. A calculating machine of at least 10 column capacity.

98. (CM) Symbols and Abbreviations

The following symbols and abbreviations are use in computations:

a. A—Integrator presetting correction parameter. Used in correcting integrator presetting Q. Action necessary because of the rounding off of E_t to E.

b. B—Integrator presetting correction parameter. Used in correcting integrator presetting S. Action necessary because of the round off of E_t to E.

c. d—Indicates difference when used as a prefix.

d. E—Angle of elevation of the range-measuring accelerometer rounded to the nearest 0.1°.

e. E_t—Value of E corresponding to cutoff signal time t.

f. E_L—Easting of the launcher.

g. E_T—Easting of the target.

h. F—Time in seconds required for range accelerometer to achieve a velocity output of 720 meters per second.

i. FS—Calibrated thrust in pounds from Thrust Unit log book.

j. h_L—Altitude of launcher location.

k. h_T—Altitude of target.

l. H—Velocity output of the lateral accelerometer at the end of 100 seconds.

m. I—The time set on the velocity timer for presetting Q in the range computer.

n. J—The time set on the displacement timer for presetting S in the range computer.

o. K_T—Geodetic azimuth of a line from launcher to target.

p. K—Aiming or firing azimuth. (Difference between K_T and K is due to the rotation of the earth.)

q. L—Dial setting for cutoff equation constant T.

r. M—Dial setting for cutoff equation constant N.

s. N—One of two cutoff equation constants.

t. N_L—Northing of the launcher.

u. N_T—Northing of the target.

v. P—Calibration value for presetting E in the missile.

w. Q—Missile's velocity presetting.

x. R_h—Effective range angle. Used in determining argument R_t for firing table entry and in computing the interpolation factor.

y. R_t—An adjusted R_h used only for firing table entry in computing the interpolation factor and times t_a and t_b.

z. R—Range angle determined by position of launcher and target.

aa. S—Missile displacement presetting.

ab. SI—Required specific impulse.

ac. SI0—Calibrated specific impulse from thrust unit log book.

ad. SIP—Change in specific impulse due to standard missile conditions.

ae. T—One of two cutoff equations.

af. t—Standard cutoff signal time corresponding to effective range angle R_h.

ag. TA—Alcohol temperature required.

ah. TB—Desired burning time.

ai. TC—Cutoff signal time.

aj. TT—Total computed flight time.

ak. TAO—Initial alcohol temperature.

al. TBM—Maximum burning time.

am. WL—Liftoff weight in pounds.

an. X—Alinement amplifier bias setting. Used to offset the effect of the component of the earth's rotation in the X axis.

ao. Y—Alinement amplifier bias setting. Used to offset the effect of the component of the earth's rotation in the Y axis.

ap. Z—Alinement amplifier bias setting. Used to offset the effect of the component of the earth's rotation in the Z axis.

aq. ϕ_L—Geodetic latitude of the launcher location.

ar. ϕ_T—Geodetic latitude of the target.

99. (CM) Determination of Basic Data

a. General.

(1) When the launcher and the target are not in the same universal transverse mercator grid zones (TM 5–241), the universal transverse mercator grid coordinates of one zone must be transformed into corresponding coordinates of the other zone before computing range angle, target azimuth, and launcher latitude.

(2) Target and launcher locations for distance and azimuth computations will normally be furnished the Redstone units in terms of universal transverse mercator grid coordinates. If locations are given in geographic coordinates only, the universal transverse grid coordinates can be computed by using volume I of the universal transverse mercator grid tables for the proper spheroid. Conversely, if locations are given in terms of universal transverse mercator grid coordinates, they may be transformed by using volume II of the

universal transverse mercator grid tables for the proper spheroid.

(3) For distance and azimuth computations, universal transverse mercator grid coordinates must be based on the same universal transverse mercator zone. Zone to zone transformation of universal transverse mercator grid coordinates for the target may be performed by using the formulas and tables in TM 5–241–2.

b. Basic Data Obtained From Worksheets 1, 2, 3, and 4.

(1) The purpose of worksheet (WS) 1, which is applicable only after the coordinates of both firing position and target have been transformed to the same UTM zone, is to determine basic data which is used in subsequent computations. This consists of the geodetic latitude of the launcher location, the geodetic azimuth of the target, and the range angle. The range angle is a central angle between the launcher location and target, with its vertex at the center of the earth, and represents an equivalent range. This angle (corrected for launcher and target altitudes) is used in worksheet 4 to determine two cutoff time values which are used as arguments for entering the firing tables for all other parameters. Also, the range angle is used to determine a time interpolation factor which is applied to all subsequent parameter calculations. The target azimuth and latitude of launcher are used in worksheet 2.

(2) The purpose of worksheet 2 is to compute and assemble data which is used in subsequent computations.

(3) The purpose of worksheet 3 is to apply corrections to firing table values when the target or launcher or both are at other than sea level altitude. This is accomplished by calculating a value R_h which is used as the argument for determining the interpolation factor IF. This value R_h is expressed as a function of the range angle R. It is based upon the launcher location, target location, the altitudes H_L and H_T of the launcher and target respectively, the target azimuth K_T, and the latitude ϕ_L of the launcher.

(4) The computations on worksheet 4 have three functions:

(*a*) Determination of two values of t, t_a and t_b, from among those values of t tabulated in the R section of the firing tables.

(*b*) Determination of two range angles R_a and R_b, corresponding to the two values of t, t_a and t_b respectively.

(*c*) Determination of an interpolation factor (IF) using range angles R_a and R_b. This interpolation factor is used in subsequent computations.

c. Worksheet 1 (fig. 24).

(1) *Determination of basic data.* The purpose of Worksheet 1, which is applicable only after the coordinates of both firing position and target have been transformed to the same UTM zone, is to determine basic data which is used in subsequent computations. This consists of the geodetic latitude of the launcher location, the geodetic azimuth of the target, and the range angle.

(*a*) Lines 1, 2, 5, 6 — Known data consisting of northing$\times 10^{-6}$ and (easting$-500{,}000$)$\times 10^{-6}$ of launcher and target.

Line 3 — Determination of dN.

Line 7 — Determination of dE.

(*b*) Both of these values (lines 3 and 7) are used in determining direction (grid bearing) (line 11) and grid distance (line 13).

Lines 4, 8, 9 — These values are used in subsequent operations.

Note. Trigonometric tables to be used will have tabulated data for angles in degrees and decimal fractions of a degree instead of degrees, minutes, and seconds.

(*c*) Line 14 — The value ϕ_L is the geodetic latitude of the foot of the perpendicular from the launcher to the central meridian of the zone.

$\phi_L = \phi'_L - (\text{VII})\, q_L^2$, where $q_L = 0.000001 E_L$. ϕ'_L is obtained from the appropriate TM 5–241–( ) series using N_L as the argument for entering the tables of function (1) if the launcher is in the Northern Hemisphere. If the launcher is in the Southern Hemisphere, use $(10{,}000{,}000 - N_L)$ as the argument. Inverse interpolation is required.

Lines 15, 16, 17 — Tables (VII), (XV), and (XVI) of appropriate volume II of TM 5–241–( ) series using the argument ϕ'_L.

Line 18 — Table (XVIII) is entered by using the argument of average northing (line 4). This table is located in the back of the technical manuals listed in paragraph 97*c*.

(2) The range of the missile is determined by using the precise angular relationship between two points on the sea-level surface of the earth with the vertex at the center of the earth.

DETERMINATION OF BASIC DATA

	(1)	N (Launcher) × 10^{-6}	6.646963	5	$N_L \times 10^{-6}$
	(2)	N (Target) × 10^{-6}	6.654755	5	$N_T \times 10^{-6}$
	(3)	(2) - (1)	0.007792	6	$\Delta N \times 10^{-6}$
	(4)	$\left[\left[(1) + (2)\right] \div 2\right] \times 10^6$	6650859	0	Mean Northing
	(5)	$(E_L - 500{,}000) \times 10^{-6}$	-0.153691	5	E'_L
	(6)	$(E_T - 500{,}000) \times 10^{-6}$	0.153368	5	E'_T
	(7)	(6) - (5)	0.307059	6	$\Delta E \times 10^{-6}$
	(8)	2 × (5)	-0.307382	6	$2E'_L \times 10^{-6}$
	(9)	(6) + (8)	-0.154014	6	$\left[2E'_L + E'_T\right] \times 10^{-6}$
Case I	(10)	(7) ÷ (3)		7	Positive value only.
Case I	(11)	$\tan^{-1}$ (10)		5	Use Case I When
Case I	(12)	cos (11)		7	(7) ≤ (3), numerically.
Case I	(13)	$\left[(3) \div (12)\right] \times 10^6$		0	R_g. Positive value only.
Case II	(10)	(3) ÷ (7)	0.0253762	7	Positive value only.
Case II	(11)	$\cot^{-1}$(10)	88°54636	5	Use Case II when
Case II	(12)	sin (11)	0.9996782	7	(7) > (3), numerically.
Case II	(13)	$\left[(7) \div (12)\right] \times 10^6$	307158	0	R_g. Positive value only.
	(14)	ϕ_L (Compute to nearest .1 of a second.)	59°57'31.2"		From DA TM 5-241-( )/2 (Appropriate spheroid) Col. (1): Argument: (1) × 10^6 in N Lat.*
	(15)	Table VII	4372	0	From DA TM 5-241-( )/2 (Appropriate spheroid) Argument: (14)
	(16)	Table XV	55799	0	From DA TM 5-241-( )/2 (Appropriate spheroid) Argument: (14)
	(17)	Table XVI	1817	0	From DA TM 5-241-( )/2 (Appropriate spheroid) Argument: (14)
	(18)	Table XVIII	0.012258	6	From DA TM 5-241-( )/2 (Appropriate spheroid) Argument: (4)
	(19)	$\left[(5)^2 + (5)(6) + (6)^2\right] \div 3$	0.0078571	7	

*If launcher is in Southern Hemisphere use as argument 10,000,000 - $\left[(1) \times 10^6\right]$

Figure 24. (CM) *Example of worksheet 1.*

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Worksheet I
Page 2

DETERMINATION OF BASIC DATA

	(20)	(18) x (19)	0.0000963 $\underline{7}$	
	(21)	[1 + (20)] x 0.9996	0.9996963 $\underline{7}$	Scale factor = k
	(22)	(15) x (19)	34 $\underline{0}$	
	(23)	(4) - [30.8 x (22)]	6649312 $\underline{0}$	In Southern Hemisphere use [10,000,000 - (4)] - [30.8 x (22)]
	(24)	Mean Radius Vector	6632321 $\underline{0}$	Radius Vector Table. (Appropriate Spheroid) Arg. (23)
	(25)	(13) ÷ (21)	307251 $\underline{0}$	Sea Level Distance, Pos. only.
R	(26)	[57.29578 x (25)] ÷ (24) = R	2°76694 $\underline{5}$	Range Angle
	(27)	$(5)^2$	0.0236209 $\underline{1}$	
	(28)	(5) x (16)	3576 $\underline{0}$	All values positive.
	(29)	(5) x (27)	0.0036303 $\underline{7}$	All values positive.
	(30)	(17) x (29)	6.6 $\underline{1}$	
	(31)	(3) x (9)	-0.00120 $\underline{5}$	
	(32)	68,755 x (18)	843 $\underline{0}$	
	(33)	[(31) x (32)] ÷ 3600	-0.00028 $\underline{5}$	
	(34)	[(28) - (30)] ÷ 3600	-2°38039 $\underline{5}$	-2° 22' 49".4 See Note 4
	(35)	(11) converted to grid az.	88°54636 $\underline{5}$	Use Note 1.
	(36)	(35) + (33)	88°54608 $\underline{5}$	
K_T	(37)	(36) ± (34) = K_T	86°16569 $\underline{5}$	See Note 2.
	(38)	(14)	59°95867 $\underline{5}$	Converted to decimals of a degree, 1/60 (min) + 1/3600(sec)
	(39)	[(15) x (27)] ÷ 3600	0°02869 $\underline{5}$	
ϕ_L	(40)	(38) - (39) = ϕ_L	59°92998 $\underline{5}$	See Note 3.

NORTHERN HEMISPHERE

Note 1
1. If (3) is + and (7) is +, (35) = (11)
2. If (3) is - and (7) is +, (35) = 180° - (11)
3. If (3) is - and (7) is -, (35) = 180° + (11)
4. If (3) is + and (7) is -, (35) = 360° - (11)

Note 2 (Launcher in Northern Hemisphere)
1. When E < 500,000, use (-) sign for (34)
2. When E > 500,000, use (+) sign for (34)

Note 3 (Launcher in Northern Hemisphere)

ϕ_L is (+)

SOUTHERN HEMISPHERE

Note 1
1. If (3) is + and (7) is +, (35) = (11)
2. If (3) is - and (7) is +, (35) = 180° - (11)
3. If (3) is - and (7) is -, (35) = 180° + (11)
4. If (3) is + and (7) is -, (35) = 360° - (11)

Note 2 (Launcher in Southern Hemisphere)
1. When E < 500,000, use (+) sign for (34)
2. When E > 500,000, use (-) sign for (34)

Note 3 (Launcher in Southern Hemisphere)

ϕ_L is (-)

Note 4 Convert to degrees, minutes and seconds.

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Figure 24. (CM)—Continued.

The process of converting the UTM coordinates to the range angle is as follows:

(*a*) Determine the scale factor K by solving the equation $K=k_0\ [1+(XVIII)q^2]$ where $k_0=.9996$ is the scale factor at the central meridian. These computations are performed on lines 19, 20, and 21. (Because of long distances, the q^2 value in the above equation is replaced by an average q^2 denoted by q^{-2}.)

$$q^{-2}=\frac{q_L^2+q_Lq_T+q_T^2}{3} \qquad \text{(line 19)}$$

(*b*) Determine the mean radius vector by using the Radius Vector Table.

Line 23	Represents a correction value in distance necessitated by the curvature of latitude for points not located at the central meridian.
Line 24	The average northing minus the latitude curvature correction provides the argument for entering the Radius Vector Tables.
Line 25	The (line 13) grid range is corrected by the scale factor K to obtain the sea level distance.
Line 26	The constant, degrees per radian, times the sea level distance divided by the mean radius vector equals the range angle in degrees.

(3) The geodetic azimuth or K_T value is determined by using the following procedure: Case I: $\tan t=\frac{DE}{DN}$

(*a*) Step 1	Case II: $\cot t+\frac{DN}{DE}$ (where t is the grid azimuth)
(*b*) Step 2	(T−t) correction due to curvature of long azimuth lines.
(*c*) Step 3	(C) correction for angle between grid north and true north.
(*d*) Line 11	Determines the bearing angle on $\frac{dE.}{dN}$ This value, when used with chart at bottom of the page (note 1), determines the grid azimuth of the target (line 35).

(*e*) (T−t) correction is applied by solving the equation $(T-t)=L(N_T-N_L)$ where T=projected geodetic azimuth and $L=6.8755\times10^{-8}$ (XVIII) $(2E'_L+E'_T)$. These computations are performed on lines 9, 31, 32, and 33.

(*f*) Convergence (C) is applied by solving the equation $C=(XV)q_L-(XVI)q_L^3$. These computations are performed on lines 27, 28, 29, and 30.

Note. In this equation, q_L must be considered as positive only.

(*g*) Convergence (C) is converted to degrees, minutes, and seconds, so that it may be applied to the grid azimuth of the orienting line on the FDC basic data record.

(4) Lines 38, 39, 40 solve the equation $\emptyset_L=\emptyset'_L-(VII\ q_L^2)$

d. Worksheet 2 (fig. 25).

(1) Section I is used to compute and tabulate the trigonometric coefficients sin $\emptyset_L$, sin 2 $\emptyset_L$, cos $\emptyset_L$, cos 2$\emptyset_L$, sin K_T, cos K_T, sin 2 K_T, cos 2 K_T, and certain of their products as listed on the worksheet. It is also used to determine the force of gravity at the launcher (lines 22, 25 through 29) and certain trigonometric values which are used in the target azimuth equation (lines 19 through 21, 30 through 32). The value of each h_T on line 4 must include the altitude of the target plus the height of burst of the warhead above the target.

(2) Section II is used to determine the proper sign of the sine and cosine of the angles used in section I. The symbol α (alpha) represents the angle used to enter the trigonometric tables. For example, if the angle is 200°, alpha would equal 20°, and the sine of 200° would be the minus value of the sine of 20°, and the cosine of 200° would be the minus value of the cosine of 20°.

(3) Section III is used to tabulate values determined and used in subsequent operations.

e. Worksheet 3 (fig. 26).

(1) Computations on worksheet 3 are performed as follows:

(*a*) Step 1—From worksheets 1 and 2, record on lines 1 through 5 the indicated values. Perform the computation indicated on lines 6 through 8.

(*b*) Step 2—Enter the firing tables and locate the appropriate R_h section. Record all values of $R_h(1)$ to $R_h(12)$ on worksheet 3 in the appropriate blocks, 9 through 20.

(*c*) Step 3—Perform the indicated computation, lines 21 through 32 to determine values for R_h and R_t.

(2) The parameter R_t is an adjusted R_h whose only function is as an argument for entry into the R section of the firing tables to determine the time interval within which the required range angle R must lie. Once R_t has served this function, it is never used again.

f. Worksheet 4 (fig. 27). Computations on worksheet 4 are performed as follows:

(1) Step 1—Using the value R_t (from worksheet 3) as the argument, enter the R section of the firing tables.

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Worksheet 2

SECTION I

(1)	K_T (From WS #1)	86°.16569	5
(2)	θ_L (From WS #1)	59°.92998	5
(3)	h_L	1235	0
(4)	h_T	730	0
(5)	2 x (1)	172°.33138	5
(6)	2 x (2)	119.85996	5
(7)	Sin (1)	0.9977616	7
(8)	Sin (2)	0.8654137	7
(9)	Sin (5)	0.1334434	7
(10)	Sin (6)	0.8672448	7
(11)	Cos (1)	0.0668714	7
(12)	Cos (2)	0.5010580	7
(13)	Cos (5)	-0.9910564	7
(14)	Cos (6)	-0.4978818	7
(15)	(12) (7)	0.4999364	7
(16)	(12) (11)	0.0335064	7
(17)	(14) (9)	-0.0664390	7
(18)	(14) (13)	0.4934289	7
(19)	(3) (4) x 10^{-6}	0.90155	6
(20)	(8) (3) x 10^{-3}	1.0687859	7
(21)	(8) (4) x 10^{-3}	0.631752	7
(22)	$(8)^2$	0.7489409	7
(23)	(10) (7)	0.8653036	7
(24)	(10) (11)	0.0579939	7
(25)	$(10)^2$	0.7521135	7
(26)	.051723 (22)	0.038737	6
(27)	.0000577 (25)	0.000043	6
(28)	(3) .3086 x 10^{-5}	0.003811	6
(29)	9.78049 + (25) -(27) - (28)	9.81537	5
(30)	(16) (3) x 10^{-3}	0.0413804	7
(31)	(16) (4) x 10^{-3}	0.0244597	7
(32)	(16) (19)	0.0302077	7

SECTION II

	360 + α	450 + α	540 + α	630 + α
	α	90 + α	180 + α	270 + α
Sin	+ Sin α	+ Cos α	- Sin α	- Cos α
Cos	+ Cos α	- Sin α	- Cos α	+ Sin α

(α less than 90°)

SECTION III

IF	0.2996	4

t_a	103
t_b	104

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Figure 25. (CM) *Example of worksheet 2.*

R_h

Worksheet 3

(1)	R (From WS 1)	2°.76694 $\underline{5}$
(2)	h_L (3) From WS 2	1235 $\underline{0}$
(3)	h_T (4) From WS 2	730 $\underline{0}$
(4)	(15) From WS 2	0.4999364 $\underline{7}$
(5)	(19) From WS 2 x 10^6	901550 $\underline{0}$
(6)	$(2)^2$	1525225 $\underline{0}$
(7)	$(3)^2$	532900 $\underline{0}$
(8)	(7) x (3) x 10^{-4}	38902 $\underline{0}$
(9)	$R_h(1)$	177.4206 $\underline{4}$
(10)	$R_h(2)$	-35.8998 $\underline{4}$
(11)	$R_h(3)$	435.2882 $\underline{4}$
(12)	$R_h(4)$	19.1335 $\underline{4}$
(13)	$R_h(5)$	0.0442 $\underline{4}$
(14)	$R_h(6)$	0.0164 $\underline{4}$
(15)	$R_h(7)$	-0.0242 $\underline{4}$
(16)	$R_h(8)$	-0.0096 $\underline{4}$

(17)	$R_h(9)$	-752.3912 $\underline{4}$	
(18)	$R_h(10)$	-42.9201 $\underline{4}$	
(19)	$R_h(11)$	-81.1256 $\underline{4}$	
(20)	$R_h(12)$	10.1014 $\underline{4}$	
(21)	[(9) + (10) (4)] (2)	196949 $\underline{0}$	
(22)	[(11) + (12) (4)] (3)	337883 $\underline{0}$	
(23)	(13) (6) + (14) (7) + (15) (5) + (16) (8)	8207 $\underline{0}$	
(24)	[(21) + (22) + (23)] x10^{-8}	0.0054430 $\underline{6}$	
(25)	[(17) + (18) (4)] (2)	-955703 $\underline{0}$	
(26)	[(19) + (20) (4)] (3)	-55535 $\underline{0}$	
(27)	[(25) + (26)] x 10^{-8}	-0.010112 $\underline{6}$	
(28)	1 + (27)	0.989888 $\underline{6}$	
(29)	(1) + (24)	2°.772370 $\underline{6}$	
(30)	(29) ÷ (28)	2°.80069 $\underline{5}$	R_h
(31)*	(30) + [(4) x 10^{-2}]	$\underline{5}$	R_t
(32)**	(30) - [(4) x 10^{-2}]	2°.79569 $\underline{5}$	R_t

* Use for Short Ranges. R < 1°.643
** Use for Long Ranges. R ≥ 1°.643

Figure 20. (CM) *Example of worksheet 3.*

(2) Step 2—Compare the R_t value with those values in the R(1) column of the R section of the firing tables.

(3) Step 3—Select the R(1) value closest to the R_t value. Extract the corresponding value of t and record this value in the t block of column (1).

(4) Step 4—Extract tabulated data for R(1), R(2), R(3), R(4), R(5), and R(6) opposite the t value determined in step 3. Record in column (1).

(5) Step 5—Extract appropriate values from worksheet 2 and record in column (2).

(6) Step 6—Cumulatively multiply column (1) by column (2) and record the cumulative total in column (4).

(7) This value is compared to the R_h value. If the total in column (4) is smaller than the R_h value, this column becomes R_a and t becomes t_a. If larger, it becomes R_b and t becomes t_b.

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R

Worksheet 4

R_t <u>2.80069</u>
(From WS 3)

	(1) From Firing T	(2) From WS 2	(3) From Firing T	(4) a b	(5) a b
t	a b 103		a b 104		
R(1)	2.78720 $^{\underline{5}}$		2.82049 $^{\underline{5}}$	2.78720 $^{\underline{5}}$	2.82049 $^{\underline{5}}$
R(2)	0.01919 $^{\underline{5}}$	0.49994 $^{\underline{5}}$ (15)	0.01981 $^{\underline{5}}$	+ 2.796794 $^{\underline{6}}$	+ 2.830394 $^{\underline{6}}$
R(3)	0.00026 $^{\underline{5}}$	−0.99106 $^{\underline{5}}$ (13)	0.00027 $^{\underline{5}}$	− 2.796536 $^{\underline{6}}$	− 2.830126 $^{\underline{6}}$
R(4)	0.00027 $^{\underline{5}}$	0.49343 $^{\underline{5}}$ (18)	0.00028 $^{\underline{5}}$	+ 2.796669 $^{\underline{6}}$	+ 2.830264 $^{\underline{6}}$
R(5)	0.01209 $^{\underline{5}}$	−0.49788 $^{\underline{5}}$ (14)	0.01220 $^{\underline{5}}$	− 2.790650 $^{\underline{6}}$	− 2.824190 $^{\underline{6}}$
R(6)	−0.00009 $^{\underline{5}}$	0.05799 $^{\underline{5}}$ (24)	−0.00010 $^{\underline{5}}$	− 2.790645 $^{\underline{6}}$	− 2.824184 $^{\underline{6}}$
			Total	2.79065 $^{\underline{5}}$	2.82418 $^{\underline{5}}$
				$(R_b - R_a) = \Delta R$	0.03354 $^{\underline{5}}$
			$(R_b - R_a) \div \Delta R = IF$		0.2996 $^{\underline{4*}}$

t_a	103 *
t_b	104 *

*Enter these values on WS 2

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Figure 27. (CM) *Example of worksheet 4.*

100. (CM) Determination of Presetting Data

a. General. Worksheets 5 through 15 are used for the determination of presetting data. The same basic pattern established in worksheet 4 is used for these 11 worksheets. Differences from the basic pattern are discussed in detail.

b. Worksheet 5 (fig. 28). Worksheet 5 is used to solve the formula $K=K_T+K(1) \text{ Sin } \emptyset_L+K(2) \text{ Sin } 2\emptyset_L \text{ Sin } K_T+K(3) \text{ Cos } \emptyset_L \text{ Cos } K_T +K(4) \text{ Sin } 2K_T+K(5) \text{ Cos } 2\emptyset_L \text{ Sin } 2K_T+[[(K(6) \text{ Sin } \emptyset_L+K(7) \text{ Cos } \emptyset_L \text{ Cos } K_T]h_L+[(K(8) \text{ Cos } \emptyset_L \text{ Cos } K_T]h_L h_T\times10^{-3}+[K(9) \text{ Sin } \emptyset_L+K(10) \text{ Cos } \emptyset_L \text{ Cos } K_T]h_T]\times10^{-3}$. The value of K is the aiming or firing azimuth that will be transmitted to the launcher. The difference between K_T, the target azimuth, and K, the firing azimuth, is the correction for rotation of the earth.

(1) Step 1—Transfer the value of K_T from WS 1 and record it in the appropriate blocks under columns a and b.

(2) Step 2—Enter the firing tables, using arguments t_a and t_b previously determined on worksheet 4, in the K section and extract tabulated data for K(1), K(2), K(3), K(4), K(5), K(6), K(7), K(8), K(9), and K(10).

(3) Step 3—Record firing table data in column (1).

(4) Step 4—Record data from worksheet 2 in appropriate blocks of column (2).

(5) Step 5—Cumulatively multiply the items in column (1) by those in column (2) and record the total products in columns a and b.

(6) Step 6—Apply interpolation factor and determine value for K. Convert K to degrees, minutes, and seconds.

c. Worksheet 6 (fig. 29).

(1) The purpose of worksheet 6 is to facilitate the solution of the formulas given below.

(*a*) Chart I.

1. $X=500 (1-\text{Cos } \emptyset_L \text{ Cos } K)$.

2. $Y=500 (\text{Sin } \emptyset_L+1)$.

3. $Z=500 (\text{Cos } \emptyset_L \text{ Sin } K+1)$.

(*b*) Chart II. $E=E(1)+E(2) \text{ Cos } \emptyset_L \text{ Sin } K$.

(2) Chart I computations determine the alinement amplifier bias settings X, Y, and Z. These settings are necessary to offset the effects of the earth's rotation on the stable platform in the X, Y, and Z axes.

(3) Chart II is a procedure to determine the range accelerometer elevation angle above the local horizon. The setting or E value is rounded off to the nearest 0.1°. This is necessary because of setting limitations in the guidance equipment. The difference $(E-E_h)$ is applied as a correction to the parameters for velocity (Q) and displacement (S).

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K

Worksheet 5

		(1) From Firing Table	(2) From WS 2	(3) a	(4) b
K_T				86.°16569 $\underline{5}$	(1) From WS 2
				(1) From WS 2	86.°16569 $\underline{5}$
K(1)	a	-1.5444 $\underline{4}$	0.86541 $\underline{5}$	-84.82915 $\underline{5}$	
	b	-1.5503 $\underline{4}$	(8)		-84.82404 $\underline{5}$
(K2)	a	-0.0044 $\underline{4}$	0.86530 $\underline{5}$	-84.82534 $\underline{5}$	
	b	-0.0046 $\underline{4}$	(23)		-84.82006 $\underline{5}$
K(3)	a	1.0376 $\underline{4}$	0.03351 $\underline{5}$	+84.86011 $\underline{5}$	
	b	1.0367 $\underline{4}$	(16)		+84.85479 $\underline{5}$
K(4)	a	-0.0004 $\underline{4}$	0.13344 $\underline{5}$	-84.86006 $\underline{5}$	
	b	-0.0003 $\underline{4}$	(9)		-84.85475 $\underline{5}$
K(5)	a	-0.0004 $\underline{4}$	-0.06644 $\underline{5}$	+84.86009 $\underline{5}$	
	b	-0.0004 $\underline{4}$	(17)		+84.85478 $\underline{5}$
K(6)	a	-0.0024 $\underline{4}$	1.06879 $\underline{5}$	-84.85752 $\underline{5}$	
	b	-0.0023 $\underline{4}$	(20)		-84.85232 $\underline{5}$
K(7)	a	0.0088 $\underline{4}$	0.04138 $\underline{5}$	+84.85789 $\underline{5}$	
	b	0.0088 $\underline{4}$	(30)		-84.85269 $\underline{5}$
K(8)	a	0.00011 $\underline{5}$	0.03021 $\underline{5}$	+84.85789 $\underline{5}$	
	b	0.00010 $\underline{5}$	(32)		+84.85269 $\underline{5}$
K(9)	a	0.0053 $\underline{4}$	0.63175 $\underline{5}$	+84.86124 $\underline{5}$	
	b	0.0052 $\underline{4}$	(21)		+84.85597 $\underline{5}$
K(10)	a	-0.0037 $\underline{4}$	0.02446 $\underline{5}$	-84.86115 $\underline{5}$	
	b	-0.0036 $\underline{4}$	(31)		-84.85589 $\underline{5}$
			Total	84.8612 $\underline{4}$	84.8559 $\underline{4}$
				$(K_b - K_a) = \Delta K$	-0.0053 $\underline{4}$

$\Delta K \times IF$ (WS 2)	-0.0016 $\underline{4}$
$(\Delta K)(IF) + (K_a) = K$	84.° 8596 $\underline{4}$
K	84° 51' 34.6" *

*Degrees, Minutes, Seconds

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Figure 28. (CM) *Example of worksheet 5.*

(4) Step 1—Complete Chart I.

(*a*) Line 1. Determine Sin value of azimuth K (from worksheet 5).

(*b*) Line 2. Determine Cos value of azimuth K (from worksheet 5).

(*c*) Lines 3 and 4. Record trigonometric coefficients from worksheet 2.

(*d*) Lines 5 through 9. Complete the indicated computations.

(5) Step 2—Complete Chart II.

(*a*) Enter firing tables in E section (arguments t_a and t_b) and extract data for E(1) and E(2). Values for E(1) and E(2) are recorded in column (1).

(*b*) Extract data from Chart I (above), line 8 and record in column (2).

(*c*) Cumulatively multiply column (1) by column (2) and determine total for columns (a) and (b). Complete indicated computations.

(*d*) Apply interpolation factor. Determine value for E_h.

(*e*) Round off E to nearest 0.1°; this value is used on worksheet 14.

(*f*) Determine the difference ($E-E_h$) and apply to worksheets 11 and 12.

(*g*) Determine the calibration setting P for presetting E in the missile.

d. Worksheet 7 (fig. 30).

(1) Worksheet 7 facilitates the solution of the formulas:

(*a*) $A=A(1)+A(2) \text{ Cos } \beta_L \text{ Sin } K_T$.

(*b*) $B=B(1)+B(2) \text{ Cos } \beta_L \text{ Sin } K_T$.

(2) The value A is a correction applied to the presetting Q (velocity). The value B is a correction applied to the presetting S (displacement). These corrections are necessary because of the rounding of E to the nearest 0.1°.

(3) The procedure outlined below is used for both A and B.

(*a*) Step 1—Using the argument t_a, enter the A and B sections of the firing tables and extract data for A(1), A(2), B(1), and B(2). The a values of A(1), A(2), B(1), and B(2) are recorded in column (1).

(*b*) Step 2—Extract from worksheet 2, the appropriate data and record in column (2).

(*c*) Step 3—Cumulatively multiply column (1) by column (2) and record the total product in appropriate blocks in column (3).

(*d*) Step 5—Round off to two decimal places and transfer the A value to worksheet 11 and the B value to worksheet 12.

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Worksheet 6

Chart I

EARTH ROTATION BIAS

(1)	Sin K (WS 5)		0.99598	5
(2)	Cos K (WS 5)		0.08960	5
(3)	(8) from WS 2		0.86541	5
(4)	(12) from WS 2		0.50106	5
(5)	500 - 500 (4) (2)	X	478	0
(6)	500 - 500 (3)	Y	933	0
(7)	500 + 500 (4) (1)	Z	750	0
(8)	(4) (1)		0.49905	5
(9)	(4) (2)		0.04489	5

E

Chart II

	(1) From Firing Table	(2)	(3) (a)	(4) (b)
E(1)	a 39.042 3		39.042 3	
	b 39.139 3			39.139 3
E(2)	a -1.731 3	0.49905 5	- 38.1781 4	
	b -1.738 3	(8) Chart I		- 38.2717 4
		Total	38.1781 4	38.2717 4
			$(E_b - E_a) = \Delta E$	0.0936 4

	Δ E x IF (WS 2) = (Δ E) (IF)	0.0280	4
	$+E_a$	38.1781	4
	(Δ E) (IF) $+E_a$ = E_h	38.2061	4
	E_h (to nearest 0.1) = E	38.2	1
	E - E_h	- 0.0061	4
	(44 - E) x 10 = $^{\circ}$P	58	0

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Figure 29. (CM) *Example of worksheet 6.*

e. Worksheet 8 (fig. 31).

(1) This worksheet facilitates the solution of the formulas $TT = TT(1) + TT(2) \text{ Cos } 2\phi_L + TT(3) \text{ Cos } \phi_L \text{ Sin } K_T$.

$$TT = \frac{\overline{TT} + C(1)\, h_L + C(2)\, h_T}{1 + C(3)\, h_L + C(4)\, h_T}$$

$$TC = \frac{(t_b - t_a)\, IF + t_a}{4} + \overline{TC}$$

The value TT is the total time of flight of the missile from firing to impact. The standard launch time for a missile

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A

Worksheet 7

	(1) From Firing Table	(2) From WS 2	(3) a
A(1)	a -16.8 1		-16.8 1
A(2)	a -1.1 1	0.49994 5 (15)	-17.35 2
		Total	-17.35 2
		A	-17.4 1

B

	(1) From Firing Table	(2) From WS 2	(3) a
B(1)	a 944 0		944 0
B(2)	a 87 0	0.49994 5 (15)	987.5 1
		Total	987.5 1
		B	988 0

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Figure 80. (CM) *Example of worksheet 7.*

fired from a zero firing altitude to zero impact altitude is computed, then corrected, for firing position, and impact altitude effects. The value TT is used in worksheet 10 for computing displacement presetting variations. The value TC is the cutoff signal time. This value is used in computing the minimum required alcohol temperature.

(2) The following procedure is used for worksheet 8:

(*a*) Step 1—Complete chart I.

1. Using t_a and t_s as arguments, enter the firing tables in the TT section. Extract data for TT(1), TT(2), and TT(3). Record those values in column 1.

2. From worksheet 2, extract the appropriate values and record in column (2).

3. Cumulatively multiply column (1) by column (2) and record the total product in the appropriate a and b column. Complete the indicated computations.

4. Apply interpolation factor. Complete computations to determine TT.

(*b*) Step 2—Complete chart II.

1. Enter TT from chart I in line (1).

2. From worksheet 2, extract the appropriate values and record.

3. Enter the firing tables in the C section and extract data for C(1), C(2), C(3), and C(4). Record these values in lines (4) through (7).

4. Perform the indicated computations in lines (8) through (14) to determine total time of flight (TT).

(*c*) Step 3—Complete chart III.

1. From worksheet 4, extract the appropriate values and record in lines (1) through (3).

2. Perform the indicated computations in line (4).

3. Enter the value TC for the appropriate range in line (5).

4. Perform the indicated computations to obtain the cutoff signal time (TC).

f. Worksheet 9 (fig. 32).

(1) This worksheet facilitates the computation of the required minimum alcohol temperature to which the alcohol must be heated in order to obtain the required burning time.

(2) The following procedure is used for worksheet 9:

(*a*) Step 1—From the FDC basic data record, extract the appropriate values and record in chart I lines 1 through 5. For computation of planned missions when alcohol temperature is not available, a standard alcohol temperature of 40° F. will be used.

(*b*) Step 2—Complete the indicated computations for lines 6 through 17.

(*c*) Step 3—If the value of line 17 is greater than the value in line 11, complete chart II. If line 17 is equal to or less than line 11, complete chart III.

g. Worksheet 10 (fig. 33).

(1) Chart I of this worksheet facilitates the solution of the equation $dQ1 = -[W(1)+W(2)R+W(3)h_L]\ dWL + [F(1)+F(2)R+F(3)h_L]\ dFS - [SI(1)+SI(2)R+SI(3)h_L]\ dSI$. This value is the first velocity presetting change (dQ1) which will be applied to the value Q to compensate for variations in standard missile lift-off weight, thrust, and specific impulse.

(2) The following procedure is used for chart I:

(*a*) Step 1—Extract from worksheet 9 the appropriate data and enter in lines 1 through 4.

CHART I

		(1) From Firing T.	(2) WS 2	(3) (a)	(4) (b)
TT(1)	a	370.20249 5		370.20249	
	b	371.62940 5			371.62940 5
TT(2)	a	1.33479 5	−0.4978818 7	−369.53792 5	
	b	1.34138 5	(14)		−370.96155 5
TT(3)	a	5.97800 5	0.4999364 7	+372.52654 5	
	b	6.05118 5	(15)		+373.98676 5
			Total	372.52654 5	373.98676 5
				$TT_b - TT_a = \Delta TT$	1.46022 5

$\Delta TT \times IF$ (WS 2)	0.43748 5
$\Delta TT \times IF + TT_a = TT$	372.96402 5

CHART II

1	TT	372.96402 5
2	h_L WS 2 (3)	1235
3	h_T WS 2 (4)	730
4	C(1) From Firing Table Section C	0.00007631
5	C(2) From Firing Table Section C	−0.00491659
6	C(3) From Firing Table Section C	−0.00000145
7	C(4) From Firing Table Section C	−0.00000965
8	(4) (2)	0.09424 5
9	(5) (3)	−3.58911 5
10	(6) (2)	−0.00179 5
11	(7) (3)	−0.00704 5
12	(1) + (8) + (9)	369.46915 5
13	(10) + (11) + 1.0	0.99117 5
14	(12) ÷ (13) = TT	372.76063 5

CHART III

1	t_a (From WS 4)		103
2	t_b (From WS 4)		104
3	IF (From WS 4)		0.2996
4	(3) + (1)		103.2996
5	$\overline{TC}$	If R < 1,643": $\overline{TC}$ = 95.75	91
		If R ≥ 1,643": $\overline{TC}$ = 91.00	
6	TC = (5) + 0.25(4)		116.82490

Figure 31. (CM) Example of worksheet 8.

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TA

Worksheet 9

CHART I

1	TAO (From Log Sheet)	-25	
2	SIO (From Log Sheet)	216.7	
3	WL (From Log Sheet)	61884	
4	FS (From Log Sheet)	78000	
5	h_L (From WS 2 (3))	1235	
6	dTA = (1) - 75	- 100	1
7	SIP = (2) + 0.04312 (6)	212.388	3
8	dSIO = (7) - 215.6	-3.212	3
9	dWL = (3) - 61185	699	0
10	dFS = (1) - 78000	0	0
11	TBM = -2.9984 + 0.5625678 (7)	116.48425	5
12	- 0.00090171 (5)	-1.11361	5
13	9.0021188 (9)	1.48104	5
14	-0.000813 (10)	0	5
15	0.2682 (8)	-0.86146	5
16	TC (From WS 8)	116.82490	5
17	TB = (16) + (15) + (14) + (13) + (12) + 0.3	116.63087	5

CHART II

If TB > TBM			
18	3.39711 (17)	396.208	3
19	-0.911105 (7)	-193.508	3
20	SI = 10.1859 + (18) + (19)	212.89	2
21	(20) - 2	-2.81	1
22	TA = 75 + 23.1911 (21)	-13.4	

CHART III

If TB ≤ TBM			
18	SI = (7)		2
19	(17) - (11)		1
20	TA = (1) + 78.78 (19)		1*

* If < -25°F the minimum alcohol temperature is -25°F.
If >110°F the missile should not be fired.

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Figure 32. (CM) *Example of worksheet 9.*

(b) Step 2—Complete the indicated computations for line 4.

(c) Step 3—Extract from worksheet 1 the value R and enter in line 6.

(d) Step 4—Enter the firing tables in the W section and extract data for W(1), W(2), and W(3). Record in the appropriate blocks lines 7 through 9.

(e) Step 5—Enter the firing tables in the F section and extract data for F(1), F(2), and F(3). Record in the appropriate blocks lines 10 through 12.

(f) Step 6—Enter the firing tables in the SI section and extract data for SI(1), SI(2), and SI(3). Record in the appropriate blocks lines 13 through 15.

(g) Step 7—Complete the indicated computations for lines 16 through 28 to obtain the first velocity presetting change (dQ1).

(3) Chart II of this worksheet facilitates the solution of the equation $dQ2=ST(1)+ST(2)h_L+[ST(3)+ST(4)h_L]R$. This value is the second velocity presetting change (dQ2) which will be applied to the value Q to compensate for variations in standard missile lift-off weight, thrust, and specific impulse.

(4) The following procedure is used for chart II:

(a) Step 1—Extract from chart I the values R and h_L and enter in the appropriate block lines 1 and 2.

(b) Step 2—Enter the firing tables in the ST section and extract data for ST(1), ST(2), ST(3), and ST(4). Record in the appropriate blocks lines 3 through 6.

(c) Step 3—Complete the indicated computations for lines 7 through 11 to obtain the second velocity presetting change (dQ2).

(5) Chart VI of this worksheet facilitates the solution of the equation $dS=-(dQ1+dQ2)\ TT-0.009544\ dWL+R\ [-0.026045\ dWL-1.9636\ dSI+0.016651\ dFS]$. The solution of this equation will provide dQ the total velocity presetting change and dS the total displacement presetting changes due to variations in standard missile lift-off weight, thrust, and specific impulse.

(6) The following procedure is used for chart III.

(a) Step 1—Extract from chart I the values dWL, dFS, dSI, and R, and enter in the appropriate blocks lines 1 through 4.

(b) Step 2—Extract from worksheet 8 the value TT and enter in line 5.

(c) Step 3—Compute the indicated computations for lines 6 through 15 to obtain dQ. Enter dQ in the box at the end of chart III.

CHART I

1	dWL (From WS 9)	699	0
2	dFS (From WS 9)	0	0
3	SI (From WS 9, Chart II, line 20 or Chart III, line 18, whichever is completed.)	212.89	2
4	dSI = (3) - 215.6	-2.71	2
5	h_L (From WS 9)	1235	
6	H (From WS 1)	2* 7669	
7	W(1) From W Section In Firing T.	0.00515	
8	W(2) From W Section In Firing T.	0.001832	
9	W(3) From W Section In Firing T.	-0.000000572	
10	F(1) From F Section In Firing T.	0.00362	
11	F(2) From F Section In Firing T.	0.000751	
12	F(3) From F Section In Firing T.	-0.000000224	
13	SI (1) From SI Section In Firing T.	0.24706	
14	SI (2) From SI Section In Firing T.	0.2427	
15	SI (3) From SI Section In Firing T.	-0.000035603	
16	(9) (5)	-0.00046	5
17	(8) (6)	0.00507	5
18	(7) + (16) + (17)	0.00976	5
19	(12) (5)	-0.00028	5
20	(11) (6)	0.00208	5
21	(10) + (19) + (20)	0.00542	5
22	(15) (5)	-0.04397	5
23	(14) (6)	0.67154	5
24	(13) + (22) + (23)	0.87463	5
25	(18) (1)	6.82224	5
26	(21) (2)	0	5
27	(24) (4)	-2.37025	5
28	dQI = (26) - (25) - (27)	-4.45199	5

Figure 33. (CM) *Example of worksheet 10.*

CHART II

1	R (From Chart I)	2° 76694	
2	h_L (From Chart I)	1235	
3	ST (1)	-13.422	
4	ST (2) From ST Section in Firing T.	- 0.0018877	
5	ST (3)	5.2129	
6	ST (4)	0.0016236	
7	(6) (2)	2.00515	5
8	(5) + (7)	7.21805	5
9	(8) (1)	19.97191	5
10	(4) (2)	-2.33131	5
11	dQ2 = (3) + (10) + (9)	4.21860	5

CHART III

1	dPL (From Chart I)	699	0
2	dFS (From Chart I)	0	0
3	dSI (From Chart I)	-2.71	1
4	R (From Chart I)	2° 76694	
5	TT (From WS 8)	372.7606	4
6	-0.009544 (1)	- 6.6713	4
7	+0.026045 (1)	- 18.2055	4
8	+1.9636 (3)	5.3214	4
9	0.016651 (2)	0	4
10	(7) + (8) + (9)	-12.8841	4
11	(4) (10)	- 35.6495	4
12	(11) + (6)	- 42.3208	4
13	dQ1 (From Chart I)	- 4.4520	4
14	dQ2 (From Chart II)	4.2186	4
15	dQ = (13) + (14)	- 0.2334	4
16	(5) (15)	- 87.0023	4
17	dS = (12) - (16)	44.6815	4

dQ *	-0.233 ₃	* Enter on WS 11
⊖ **	45 ₃	** Enter on WS 12

Figure 55 (CM)—Continued.

(d) Step 4—Compute the indicated computations for lines 16 and 17 to obtain dS. Enter dS in the box at the end of chart III.

(e) Step 5—Enter the value dQ into worksheet 11. Enter the value dS into worksheet 12.

h. Worksheet 11 (fig. 34).

(1) Worksheet 11 facilitates the solution of the formula $Q=Q(1)+Q(2)\ \mathrm{Cos}\ \emptyset_L\ \mathrm{Sin}\ K_T+Q(3)\ \mathrm{Cos}\ 2\emptyset_L+Q(4)\ \mathrm{Cos}\ 2K_T+Q(5)\ \mathrm{Cos}\ 2\emptyset_L\ \mathrm{Cos}\ 2K_T+Q(6)\ \mathrm{Sin}\ 2\emptyset_L\ \mathrm{Cos}\ K_T+C_1h_L+dQ$. (For $t_a \geq 57$, $C_1=0.0134$. For $t_a<57$, $C_1=0.0126$.) The value Q is the missile velocity presetting. Three corrections have been applied—one to compensate for altitudes other than sea level, one to compensate for the rounding of E to the nearest 0.1°, and one to compensate for variations in standard missile lift-off weight, thrust, and specific impulse. The value Q is used in worksheet 14 to compute a time in seconds.

(2) The following procedure is used for worksheet 11:

(a) Step 1—Using t_a and t_b as arguments, enter the firing tables in the Q section. Extract data for Q(1), Q(2), Q(3), Q(4), Q(5), and Q(6). Record values for Q(1), Q(2), Q(3), Q(4), Q(5), and Q(6) in the appropriate blocks under column (1).

(b) Step 2—From worksheet 2, extract the appropriate values and record in column (2).

(c) Step 3—Cumulatively multiply column (1) by column (2) and record the total product in the appropriate a and b columns. Complete the indicated computations.

(d) Step 4—Apply the interpolation factor and determine a value for $\overline{Q}_h$.

(e) Step 5—Apply the correction factor necessitated by the rounding of E to the nearest 0.1°. Use values $(E-E_h)$ from worksheet 6 and A from worksheet 7. Determine a value for $\overline{Q}$.

(f) Step 6—Enter dQ from worksheet 10 and add to $\overline{Q}$ to obtain Q. This value is transferred to worksheet 14.

i. Worksheet 12 (fig. 35).

(1) This worksheet facilitates the solution of the formula $S=S(1)+S(2)\ \mathrm{Cos}\ \emptyset_L\ \mathrm{Sin}\ K_T+S(3)\ \mathrm{Cos}\ 2\emptyset_L+S(4)\ \mathrm{Cos}\ 2K_T+S(5)\ \mathrm{Cos}\ 2\emptyset_L\ \mathrm{Cos}\ 2K_T+S(6)\ \mathrm{Sin}\ 2\emptyset_L\ \mathrm{Cos}\ K_T+C_2h_L+dS$. (For $t_a \geq 57$, $C_2=-2.25$. For $t_a<57$, $C_2=-1.67$.)

(2) The value S is the missile displacement presetting. Three corrections have been applied; one to compensate for altitudes other than sea level, one to compensate for the rounding of E to the nearest 0.1° and one to compensate for variations in standard missile weight, thrust, and specific

Worksheet 11

Q

		(1) From Firing T.	(2) From WS 2	(3) a	(4) b
Q(1)	a	-2236.898 [3]		-2236.898 [3]	
	b	-2249.740 [3]			-2249.740 [3]
Q(2)	a	26.082 [3]	0.49994 [5]	-2223.8586 [4]	
	b	26.099 [3]	(15)		-2236.6921 [4]
Q(3)	a	-0.819 [3]	-0.49788 [5]	-2223.4508 [4]	
	b	-0.814 [3]	(14)		-2236.2868 [4]
Q(4)	a	-0.113 [3]	-0.99106 [5]	-2223.3388 [4]	
	b	-0.116 [3]	(13)		-2236.1718 [4]
Q(5)	a	-0.114 [3]	0.49343 [5]	+2223.3951 [4]	
	b	[3]	(16)		+2236.2295 [4]
Q(6)	a	[3]	0.05799 [5]	+2223.4159 [4]	
	b	[3]	(24)		+2236.2504 [4]
$t_a \geq 57$		.0134	1235 (3) [0]	-2206.867 [3]	-2219.701 [3]
$t_a < 57$		.0126			
			TOTAL	-2206.867 [3]	-2219.701 [3]
				$(Q_b - Q_a) = \Delta Q$	-12.834 [3]

$\Delta Q \cdot IF$ (WS 2) = (Δ Q) (IF)	-3.845 [3]
(Δ Q) (IF) + Q_a = Q_h	2210.712 [3]
$(E - E_h)$ FROM WS 6 × A FROM WS 7	0.106 [3]
$Q_h + (E - E_h)(A) = \overline{Q}$	-2210.606 [3]
dQ = (From WS 10)	-0.233 [3]
$Q = \overline{Q} + dQ$	-2210.839 [3]

Figure 34. (CM) Example of worksheet 11.

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S

Worksheet 12

		(1) From Firing T.	(2) From WS 2	(3) a	(4) b
S(1)	a	169631 0		169631 0	
	b	171035 0			171035 0
S(2)	a	-1174 0	0.49994 5	- 169044.1 1	
	b	-1173 0	(15)		- 170448.6 1
S(3)	a	82 0	- 0.49788 5	- 169003.2 1	
	b	81 0	(14)		- 170408.2 1
S(4)	a	12 0	- 0.99106 5	- 168991.4 1	
	b	12 0	(13)		- 170396.3 1
S(5)	a	12 0	0.49343 5	+ 168997.3 1	
	b	12 0	(18)		+ 170402.3 1
S(6)	a	18 0	0.05799 5	+ 168998.3 1	
	b	18 0	(24)		+ 170403.3 1
$t_a > 57$		-2.25	1235 0	- 166219.6 1	- 167624.6 1
$t_a < 57$		-1.67	(3)		
			Total	166219.6 1	167624.6 1
				$(S_b - S_a) = \Delta S$	1405.0 1

$\Delta S \times IF$ (WS 2) = (ΔS) (IF)	420.9 1
(ΔS) (IF) + $S_a = S_h$	166640.4 1
$(E - E_h)$ (WS 6) $\times$ (B) (WS 7)	- 6.0 1
$S_h + (E - E_h)$ (B) = $\bar{S}$	166634 0
dS (From WS 10)	45 0
$S = \bar{S} + dS$	166679 0

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Figure 35. (CM) Example of worksheet 12.

impulse. The value S is used in worksheet 14 to compute a time in seconds. This time is used to preset S in the missile.

(3) The following procedure is used for worksheet 12:

(*a*) Step 1—Using t_a and t_b as arguments, enter the firing tables in the S section. Extract data for S(1), S(2), S(3), S(4), S(5), and S(6). Record values for S(1), S(2), S(3), S(4), S(5), and S(6) in the appropriate boxes under column (1).

(*b*) Step 2—From worksheet 2, extract the appropriate values and record in column (2).

(*c*) Step 3—Cumulatively multiply column (1) by column (2) and record total product in the appropriate a and b columns. Complete the indicated computations.

(*d*) Step 4—Apply the interpolation factor and determine a value for $\bar{S}_h$.

(*e*) Step 5—Apply the correction factor necessitated by the rounding of E to the nearest 0.1°. Use the values $(E-E_n)$ from worksheet 6 and B from worksheet 7. Determine a value for $\bar{S}$.

(*f*) Step 6—Enter dS from worksheet 10 and add to $\bar{S}$ to obtain S. This value is transferred to worksheet 14.

j. Worksheet 13 (fig. 36).

(1) Chart I of this worksheet facilitates the solution of the equation $T=T(1)+T(2)\ \text{Cos}\ \theta_L\ \text{Sin}\ K_T+T(3)\ \text{Cos}\ 2\theta_L+C_3h_L$. (For $t_a \geq 57$, $C_3=0.00285$. For $t_a<57$, $C_3=0.00275$). This value is the first of two cutoff equation constants which are preset into the missile. The value T must be converted into another numerical value for dial setting. This is done by applying the formula $L=\left[2.75-\frac{481.25}{T}\right]10^3$ to the value T. This value is called L. It represents T as a dial setting to the value T. This value is called L. It represents T as a dial setting in seconds.

(2) The following procedure is used for chart I:

(*a*) Step 1—Using arguments t_a and t_b, enter the firing tables in the T section and extract data for T(1), T(2), and T(3). The values of T(1), T(2), and T(3) are recorded in the appropriate blocks in column (1).

(*b*) Step 2—Extract from worksheet 2 the appropriate data and record in column (2).

(*c*) Step 3—Cumulatively multiply column (1) by column (2) and record the total products in the appropriate blocks in columns a and b.

(*d*) Step 4—Apply interpolation factor and determine value for T.

T

Chart I

		(1) From Firing T.	(2) From WS 2	(3) a	(4) b
T(1)	a	228.74 $\underline{2}$		228.74 $\underline{2}$	
	b	230.07 $\underline{2}$			230.07 $\underline{2}$
T(2)	a	6.09 $\underline{2}$	0.49994 $\underline{5}$	+ 231.785 $\underline{3}$	
	b	6.16 $\underline{2}$	(15)		+ 233.150 $\underline{3}$
T(3)	a	1.38 $\underline{2}$	- 0.49788 $\underline{5}$	- 231.098 $\underline{3}$	
	b	1.39 $\underline{2}$	(14)		- 232.458 $\underline{3}$
$t_a \geq 57$		.00285	1235 $\underline{0}$ (3)	+ 234.617 $\underline{3}$	+ 235.977 $\underline{3}$
$t_a < 57$		.00275			
			Total	234.62 $= T_a$ $\underline{2}$	235.98 $= T_b$ $\underline{2}$
				$(T_b - T_a) = \Delta T$	1.36 $\underline{2}$

(1)	$\Delta T \times IF$ (WS 2) $= \Delta T \times IF$	0.407 $\underline{3}$
(2)	$(1) + T_a = T$	235.027 $\underline{3}$
(3)	481.25 ÷ (2)	2.048 $\underline{3}$
(4)	$[2,750 - (3)] \times 10^3 = L$	702 $\underline{0}$

N

Chart II

		(1) From Firing T.	(2) From WS 2	(3) a	(4) b
N(1)	a	16.71 $\underline{2}$		16.17 $\underline{2}$	
	b	16.85 $\underline{2}$			16.85 $\underline{2}$
N(2)	a	0.10 $\underline{2}$	0.49994 $\underline{5}$	+ 16.760 $\underline{3}$	
	b	0.10 $\underline{2}$	(15)		+ 16.900 $\underline{3}$
N(3)	a	0.05 $\underline{2}$	- 0.49788 $\underline{5}$	- 16.735 $\underline{3}$	
	b	0.05 $\underline{2}$	(14)		- 16.875 $\underline{3}$
$t_a \geq 57$		.000400	1235 $\underline{0}$ (3)	+ 17.229 $\underline{3}$	+ 17.369 $\underline{3}$
$t_a < 57$		.000458			
			Total	17.23 $= N_a$ $\underline{2}$	17.37 $= N_b$ $\underline{2}$
				$(N_b - N_a) = \Delta N$	.14 $\underline{2}$

(1)	$\Delta N \times IF$ (WS 2) $= \Delta N \times IF$	0.04 $\underline{2}$
(2)	$(1) + N_a = N$	17.27 $\underline{2}$
(3)	33,333 × (2) = M	576 $\underline{0}$

Figure 36. (CM) Examples of worksheet 18.

(e) Step 5—Apply calibration factor to determine L, the dial setting. Round off to nearest whole number.

(3) Chart II of this worksheet facilitates the solution of the equation $N=N(1)+N(2)\ \text{Cos}\ \emptyset_L\ \text{Sin}\ K_T+N(3)\ \text{Cos}\ 2\emptyset_L+C_4h_L$. (For $t\geq 57$, $C_4=0.0004000$. For $t_a<57$, $C_4=0.000458$) This value is the second of two cutoff equation constants which are preset into the missile. The value N in meters per second must be converted into a numerical value for dial setting. This is accomplished by multiplying N by 33.333. This product is called M and it represents N as a dial setting.

(4) The following procedure is used for chart II:

(a) Step 1—Using arguments t_a and t_b, enter the firing tables in the N section and extract data for N(1), N(2), and N(3). The values of N(1), N(2), and N(3) are recorded in the appropriate blocks in column (1).

(b) Step 2—Extract from worksheet 2 the appropriate data and record in column (2).

(c) Step 3—Cumulatively multiply column (1) by column (2) and record the total products in the appropriate blocks in columns a and b.

(d) Step 5—Apply interpolation factor. Determine value for N.

(e) Step 6—Multiply N by 33.333 to determine M, the missile dial setting. Round off to the nearest whole number.

k. *Worksheet 14* (fig. 37).

(1) The purpose to worksheet 14 is to facilitate the solution of the formulas $F=\frac{720}{Ag + Ar}$, $I=\frac{-Q}{Ag + A_r}$, and $J=\sqrt{\frac{25}{Ag + A_r}}$ where F is the value for calibrating the range accelerometer, I is the time required for presetting the velocity presetting Q, and J is the time required for presetting the displacement presetting S. $A_g=g_L\ \text{Sin E}$ and g_L is the value of gravity at the launcher. $A_r=-0.00834\ (\text{Cos K Cos E Cos}\ \emptyset_L+\text{Sin}\ \emptyset_L\ \text{Sin E})$. This is the magnitude of the apparent acceleration in the range measuring direction due to the rotation of the earth.

(2) The following procedure is used for worksheet 14:

(a) Step 1—From worksheets 2, 6, 11, and 12 extract the appropriate values and record on worksheet 14, lines 1 through 6.

(b) Step 2—Complete the indicated computations for lines 7 through 29.

(c) Step 3—Determine values for F; F+0.01 sec; F−0.01 sec; I; and J. Round off to three decimals.

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Worksheet 14

F, I, J

(1)	(8) WS 1		0.8654135 ^{7}
(2)	(29) WS 1		9.81537 ^{5}
(3)	(9) Chart 1 WS 6		0.04489 ^{2}
(4)	E Chart 2 WS 6		38.2 ^{1}
(5)	Q WS 11		-2210.835 ^{3}
(6)	S WS 12		166679 ^{0}
(7)	(4) + .01		38.21 ^{1}
(8)	(4) - .01		38.19 ^{1}
(9)	Sin (4)		0.6184084 ^{7}
(10)	Sin (7)		0.6185455 ^{7}
(11)	Sin (8)		0.6182712 ^{7}
(12)	Cos (4)		0.7858565 ^{7}
(13)	Cos (7)		0.7857485 ^{7}
(14)	Cos (8)		0.7859648 ^{7}
(15)	(1) (9)		0.5351791 ^{7}
(16)	(1) (10)		0.5352977 ^{7}
(17)	(1) (11)		0.5350604 ^{7}
(18)	(3) (12)		0.0352771 ^{7}
(19)	(3) (13)		0.0352723 ^{7}
(20)	(3) (14)		0.0352820 ^{7}
(21)	(2) (9)		6.06991 ^{5}
(22)	(2) (10)		6.07125 ^{5}
(23)	(2) (11)		6.06856 ^{5}
(24)	-.00834 [(18) + (15)]		-0.00476 ^{5}
(25)	-.00834 [(19) + (16)]		-0.00476 ^{5}
(26)	-.00834 [(20) + (17)]		-0.00476 ^{5}
(27)	(21) + (24)		6.06515 ^{5}
(28)	(22) + (25)		6.06649 ^{5}
(29)	(23) + (26)		6.06380 ^{5}
(30)	720 ÷ (27)	r	118.711 ^{3}
(31)	720 ÷ (28)	r + .01 Sec	118.685 ^{3}
(32)	720 ÷ (29)	r - .01 Sec	118.737 ^{3}
(33)	-(5) ÷ (27)	i	364.515 ^{3}
(34)	2 × (6) ÷ (27)		54963 ^{0}
(35)	$\sqrt{(34)}$	j	234.442 ^{3}

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Figure 57. (CM) Example of worksheet 14.

l. Worksheet 15 (fig. 38).

(1) The purpose of worksheet 15 is to facilitate the solution of the formula $H=100\ (L_s+L_r)$, where H is the velocity output of the lateral accelerometer at the end of 100 seconds due to the rotation of the earth at the launcher location.

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Worksheet 15

H

(1)	Sin ϕ_L (8) WS 2	0.86541	5	
(2)	g_L (29) WS 2	9.81537	5	
(3)	(8) Chart I WS 6	0.49905	5	
(4)	.0001745 (1)	0.00015	5	
(5)	-.0001745 (1)	- 0.00015	5	
(6)	.0001745 (2)	0.00171	5	
(7)	-.0001745 (2)	- 0.00171	5	
(8)	(3) - (4)	0.49890	5	
(9)	(3) - (5)	0.49920	5	
(10)	.00834 (8)	0.00416	5	
(11)	.00834 (9)	0.00416	5	
(12)	(6) + (10)	0.00587	5	
(13)	(7) + (11)	0.00245	5	
(14)	100 (12)	0.587	3	H + .01
(15)	100 (13)	0.245	3	H - .01
(16)	.834 (3)	0.416	3	H

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Figure 38. (CM) *Example of worksheet 15.*

$L_s = g_L$ Sin d

$L_r = 0.00834$ (Cos ϕ_L Sin K Cos d − Sin ϕ_L Sin d). This is the magnitude of the apparent acceleration in the lateral direction.

(2) The following procedure is used for worksheet 15:

(a) Step 1—Extract from worksheets 2 and 6 the appropriate values and record on worksheet 15, lines 1 through 3.

(b) Step 2—Complete the indicated computation for lines 4 through 13.

(c) Step 3—Determine values for H; H+0.01; and H−0.01, lines 14 through 16. Round off to three decimals.

101. (CM) Azimuth of Orienting Line

a. The aiming azimuth (K) as determined in worksheet 5 (fig. 28) is a geodetic azimuth adjusted for rotation of the earth. To orient properly the lateral accelerometer, the azimuth of the orienting line must be expressed in compatible terms.

b. Geodetic azimuth is obtained from grid azimuth by applying the convergence factor C to the grid azimuth. In many cases this factor will be virtually the same for a point on the orienting line as for the firing position. However, particularly at the higher latitudes, there may be a significant difference between these two values of C. Therefore, FDC should always receive and record the grid azimuth of the orienting line and apply to it the value of C determined for the firing position.

c. The computation for determining the geodetic azimuth of the orienting line is performed on the FDC basic data record (fig. 18) in the following manner:

(1) Survey personnel report the grid azimuth of the orienting line. This value is entered on the FDC basic data record.

(2) After completion of worksheet 1 (fig. 24), the value of convergence from line 34, worksheet 1, is entered on the FDC basic data record. Note 4 on worksheet 1 provides for converting this value to degrees, minutes, and seconds for recording on the FDC basic data record. (A proposed change for the missile programing data computer, Redstone, will provide this value of C the convergence as an additional output.)

(3) Using the proper sign, the value of C is applied to the grid azimuth of the orienting line, converting it to a geodetic azimuth (this is not actually a true geodetic azimuth, since it includes the value of convergence for the firing position rather than the orienting line). The geodetic azimuth of the orienting line is then recorded on the fire command sheet (fig. 19).

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